

1953

Pleistocene Terraces Along the Brazos and Wichita Rivers, Central and North-Central Texas.

Fred Lee Stricklin

Louisiana State University and Agricultural & Mechanical College

Follow this and additional works at: https://digitalcommons.lsu.edu/gradschool_disstheses



Part of the [Earth Sciences Commons](#)

Recommended Citation

Stricklin, Fred Lee, "Pleistocene Terraces Along the Brazos and Wichita Rivers, Central and North-Central Texas." (1953). *LSU Historical Dissertations and Theses*. 8044.
https://digitalcommons.lsu.edu/gradschool_disstheses/8044

This Dissertation is brought to you for free and open access by the Graduate School at LSU Digital Commons. It has been accepted for inclusion in LSU Historical Dissertations and Theses by an authorized administrator of LSU Digital Commons. For more information, please contact gradetd@lsu.edu.

PLEISTOCENE TERRACES
ALONG THE BRAZOS AND WICHITA RIVERS,
CENTRAL AND NORTH-CENTRAL TEXAS

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Department of Geology

By
Fred Lee Stricklin, Jr.
B. S., Louisiana State University, 1948
M. S., Louisiana State University, 1950
June, 1953

UMI Number: DP69422

All rights reserved

INFORMATION TO ALL USERS

The quality of this reproduction is dependent upon the quality of the copy submitted.

In the unlikely event that the author did not send a complete manuscript and there are missing pages, these will be noted. Also, if material had to be removed, a note will indicate the deletion.



UMI DP69422

Published by ProQuest LLC (2015). Copyright in the Dissertation held by the Author.

Microform Edition © ProQuest LLC.

All rights reserved. This work is protected against unauthorized copying under Title 17, United States Code



ProQuest LLC.
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106 - 1346

MANUSCRIPT THESES

Unpublished theses submitted for the master's and doctor's degrees and deposited in the Louisiana State University Library are available for inspection. Use of any thesis is limited by the rights of the author. Bibliographical references may be noted, but passages may not be copied unless the author has given permission. Credit must be given in subsequent written or published work.

A library which borrows this thesis for use by its clientele is expected to make sure that the borrower is aware of the above restrictions.

LOUISIANA STATE UNIVERSITY LIBRARY

ACKNOWLEDGEMENTS

The writer is gratefully indebted to Dr. R. J. Russell, Dean of the Graduate School, Louisiana State University, for his tireless advisory efforts applied during the course of work on this problem. Much of his valuable time was consumed by offering counsel, rendering guidance in the field, and reviewing the manuscript. The ideas presented herein are those of the writer, but their formulation and expression was accomplished largely under the encouragement of Dr. Russell.

Greatly appreciated suggestions were received from Dr. H. N. Fisk, Chief, Geologic Research, Humble Oil Company. Both he and Rufus J. LeBlanc, Senior Research Geologist, Shell Oil Company, reviewed the manuscript and offered invaluable advice. Indebtedness is also expressed to Dr. F. E. Lozo and Dr. H. A. Bernard, both Senior Research Geologists for Shell Oil Company, for their assistance in organization and interpretation of data. The solution of drafting and reproduction problems was made easier by Bruce Gray and R. I. MacDonald, also of Shell Oil Company. Very capable field assistance was rendered by Bob Lucas, Ike Smith, and Martin Bonora, all geology students at Baylor University in 1951-52.

TABLE OF CONTENTS

	Page
FOREWORD	1
INTRODUCTION	4
EFFECTS OF EXISTING RIVER REGIMES AND VALLEY GEOLOGY UPON THE BRAZOS AND WICHITA RIVERS	9
<u>The Brazos River</u>	9
Meandering Patterns.	10
Incised Meandering Patterns.	12
Braided Patterns	15
<u>The Wichita River.</u>	15
PROPOSED TERRACE TERMINOLOGY	18
<u>Lofers Terrace</u>	18
<u>Mixon Terrace.</u>	19
<u>Madrigal Terrace</u>	19
<u>Gerik Terrace.</u>	21
THE PLEISTOCENE TERRACES	22
<u>Mapping Methods.</u>	22
Unmodified Surfaces.	23
Dissected Surfaces	24
<u>Distribution</u>	27
Alluvial Valleys	27
Incised Valleys.	30
Upper Valleys.	36

	Page
<u>Longitudinal Profiles</u>	37
<u>Lithology</u>	41
<u>Stratigraphic Nomenclature.</u>	45
DRAINAGE REALIGNMENTS	46
<u>Recent.</u>	46
<u>Pleistocene</u>	47
Seymour Diversion	47
CORRELATIONS AND CHRONOLOGY	54
<u>The Area Investigated</u>	54
<u>Glacial Chronology.</u>	58
<u>Regional Correlations and Considerations.</u>	60
PLEISTOCENE EROSION AND SEDIMENTATION	64
<u>Stream Behavior</u>	66
<u>Influence of Glaciation upon Stream Regimes</u>	66
Volumetric Variations	67
Changes in Stream Velocities.	67
THEORIES OF TERRACE ORIGIN.	69
<u>Land Movements.</u>	69
<u>Volumetric Variations of Pleistocene Seas</u>	71
<u>Land and Sea Movements.</u>	72
ORIGIN OF THE BRAZOS RIVER TERRACES	74
<u>The Upper Valley.</u>	75
<u>The Incised Valley.</u>	77
<u>The Alluvial Valley</u>	80

ILLUSTRATIONS

	Page
Plate 1. Regional geologic map showing relationships of stream patterns to rock divisions . . .	11
2. Pleistocene terraces along Brazos River near Whitney Dam, Hill County	20
3. Lithologic interpretation of aerial photographs	25
4. Brazos River terraces.	31
5. Brazos River terraces.	32
6. Brazos River terraces.	33
7. Brazos and Wichita River terraces.	34
8. Wichita River terraces	35
9. Brazos and Wichita River profiles.	40
10. Exposures of Pearlette ash	44
11. Contoured mosaic showing evidence of stream diversion.	50
 Figure 1. Index map of the area covered by a reconnaissance-type survey	 5
2. Fluvial and coastwise terraces along the lower Brazos River	29
3. Regional outcrop map of Pleistocene deposits showing their relationship to older, graveliferous sediments (Ogallala?) that cap the High Plains.	39
4. Block diagram showing the region of the Seymour diversion.	49
5. Chart showing correlations in the area investigated	55

	Page
Figure 6. Chart showing glacial chronology of the Brazos, Trinity, and Mississippi River terraces.	61
7. Map of the incised Brazos River valley around Fort Graham, Hill County, show- ing approximate positions of Pleisto- cene stream channels.	79

ABSTRACT

Fluvial Pleistocene terrace surfaces, dissected, non-continuous, but amply distributed for correlation, occur above modern flood plains of the Brazos and Wichita Rivers, central and north-central Texas. Four such surfaces, occurring in step-like series, are recognized along the Brazos River. In ascending order topographically, from youngest to oldest geologically, these surfaces are here named the Lofers, Nixon, Madrigal, and Gerik terraces. Along Wichita River, a younger stream than the Brazos, remnants of the Lofers and Nixon terraces are present. The deposits of each terrace are mappable units recognized as formations and are designated by the same terminology proposed for their surfaces.

The terraces, distributed according to valley size, are widespread where the streams now meander or braid in poorly consolidated sediments, mostly Permian and Upper Cretaceous, and limited along walls deeply incised into Pennsylvanian and lower Cretaceous resistant beds. An abandoned valley, terraced across a divide in Baylor County, indicated that a relatively large stream, probably an ancestor of the upper Wichita River, formerly joined the Brazos River there.

A succession of antecedent valleys, separated now and terraced above modern ones, developed because the streams there, alluviating and then eroding in repeated episodes,

had their discharges changed periodically according to glacial pulsations. The several valley formations, one containing volcanic ash (Pearlette) interbedded elsewhere with glacio-fluviatile deposits, accumulated during arid or mild times, much like today, when seas, varying volumetrically according to existing ice, were at high positions. After each lengthy alluviation, when oceans shrank to low stands during moist glacial times, stream incision was progressively deeper because of erosional response then to uplift that occurred continuously during the Pleistocene.

FOREWORD

This investigation was undertaken as a result of the writer's interest in geologic history as interpreted from alluvial Pleistocene terraces. Several opposing theories of terrace origin that have evolved from work in coastal regions were examined in the light of evidence uncovered in this region in central and north-central Texas. The Pleistocene history as interpreted from fluvial terraces there involves land uplift, eustatic variations of the sea, and repeated climactic swings from mild or dry to extremely pluvial conditions. The latter two were definitely controlled by continental glaciation.

The results of this report have been gained from a reconnaissance type investigation conducted with a Paulin altimeter. Profile traverses of the terraces were constructed by establishing elevation points along the roads and highways and controlled by checking them with benchmark elevations surveyed by U. S. Coast and Geodetic Survey. A further determination of their accuracy was assured by coordinating them at bridges with river profiles issued by the U. S. Corps of Engineers. Approximately 3,000 miles of profiles were run during field work, which amounted to a total of about three months, conducted intermittently during 1950, 1951, and 1952.

Mapping was done by transferring the profile data to photograph mosaics issued by the U. S. Department of Agriculture and controlled by the density of the road network and the geologic interpretation of the photographs.

Topographic maps prepared by the U. S. Corps of Engineers during survey work for dam sites provided excellent control along the Brazos River between Whitney, Hill County, and Graham, Young County. The distribution of the terraces is presented in this report on base maps compiled from the photograph mosaics. Areas of particular significance are shown on mosaics that were constructed with large-scale photographs obtained from the Department of Agriculture. In these key areas topographic information has been obtained from the Crown Central Drilling Company and the U. S. Corps of Engineers.

Previous studies of the terraces in this region have been secondary in nature, and their results are cited as incidental information in county and mineral reports. In 1893 Cummins noted and mapped thick deposits ("Seymour beds") of Quaternary sand and gravel in Baylor and Knox Counties, but did not assign a terrace origin to them. Terraces along the Brazos River have been referred to by Winton and Scott (1922), Adkins (1923), Plummer and Hornsberger (1935), Hatch (1936), Evans (1941), Criswell (1942), and Hull (1951). In 1936 Evans described terraces along the lower Wichita

River. All these workers have designated the terraces by their heights above the adjacent streams. A reconnaissance investigation of the lower Brazos River system by Cox in 1949 revealed the presence of four extensive terraces there. He indicated them by terms (Prairie, Montgomery, Bentley, and Williana) used by Fisk, Russell, and others who have worked in the Mississippi River Valley.

INTRODUCTION

Field research for this investigation was conducted along the Brazos River from Marlin, Falls County, to Benjamin, Knox County, and along the Wichita River from Benjamin to its confluence with Red River in Clay County (Fig. 1). Terrace distribution determined the extent of the field work within each of the valleys. Along the Brazos River Paleozoic and Mesozoic strata are exposed beneath the dissected terrace deposits and on the valley walls. In the Wichita River valley only Permian beds underly the terraces. In the valley of the Brazos River near the Palo Pinto-Parker county line, Lower Cretaceous sediments lie unconformably upon Pennsylvanian beds that are tilted very gently to the west. Pennsylvanian and Permian strata are exposed beneath terraces in the valley north of this point; whereas to the south easterly dipping Upper and Lower Cretaceous beds occur with the Pleistocene deposits.

Portions of three physiographic provinces, Gulf Coastal Plain, Great Plains, and Central Lowlands, lie in the area under consideration (Fig. 1). In McLennan and Falls Counties the Brazos River flows across a portion of the Gulf Coastal Plain, and farther to the north as far as Parker County, across the Great Plains. The major physiographic features there are the Comanche Plateau and the Western

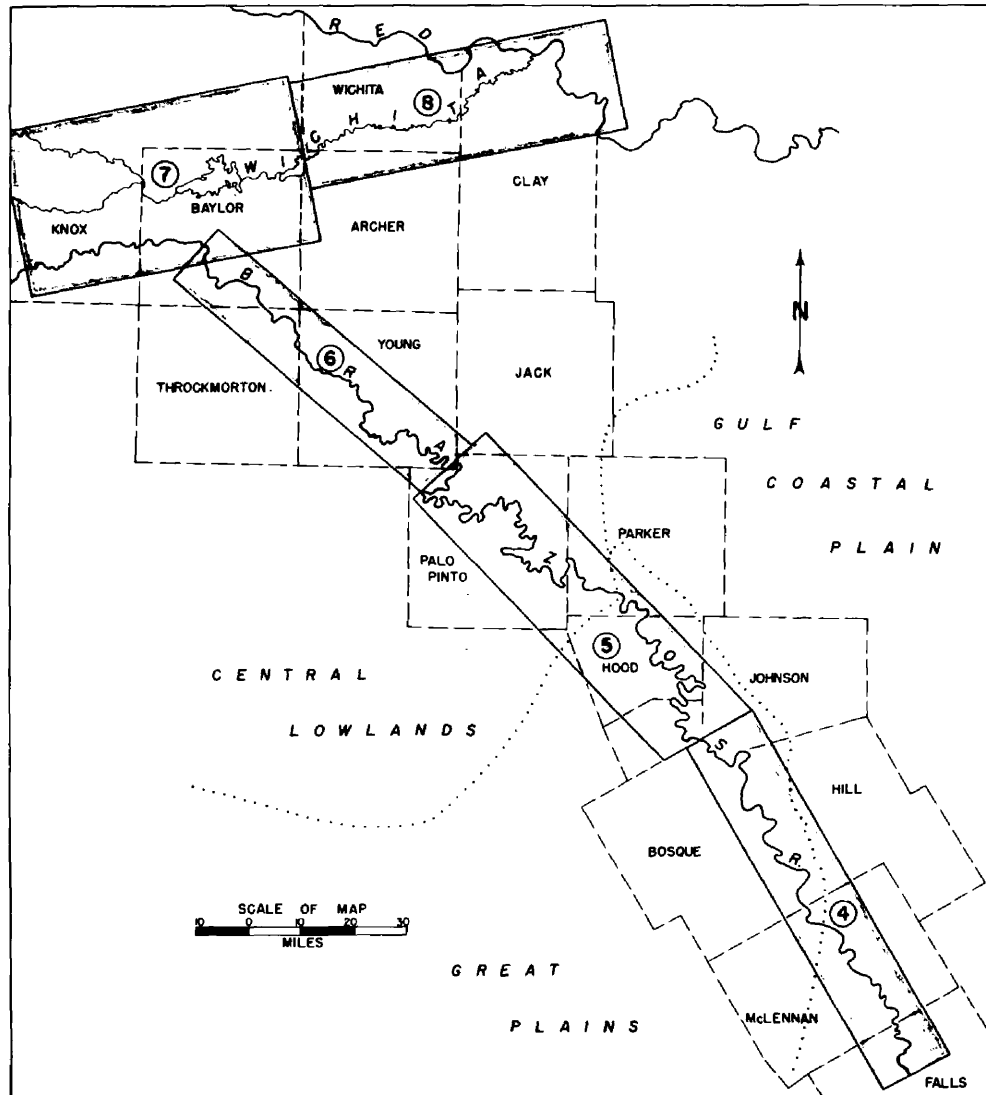


Figure 1 - Index map of the area covered by a reconnaissance-type survey. The numbered, shaded areas refer to plates showing the distribution of the terraces and their cross-sections.

Cross Timbers. The remainder of the area to the north and northwest lies in the Osage Plains of the Central Lowlands Province.

The topography of the region varies greatly. Resistant Pennsylvanian and Permian rocks support narrow, steep-walled valleys; whereas those in soft Upper Cretaceous sediments are usually wide with gentle transverse slopes. Relief is moderate in areas of Permian outcrop and becomes more rugged where resistant beds have been incised by the rivers. Undermining of Permian sediments beneath Pleistocene gravel has produced cliffs of some consequence in the Wichita River basin in Baylor and Knox Counties.

Along the streams of the area under consideration extensive deposits of Pleistocene sand, silt, and gravel occur as separate sequences lying at different valley positions. An outstanding feature of each is the alluvial terrace developed on its upper deposits, resembling and having the same origin as the modern floodplain surface lying at low elevations in the valleys. The terraces now stand well above the flood plain, not everywhere because of their dissection, and are arranged in a step-like manner. The relative valley position of each, superior height indicating greater antiquity, provides the only reliable basis for tracing equivalent surfaces.

Attempts to correlate the deposits without noticing their surfaces are prevented by similar lithologies, lack of knowledge as to the precise ranges of associated Pleistocene fossils, and the discontinuity of their occurrence.

The problem of age determination of the terraces requires a knowledge of the subdivisions of the Quaternary Period, which are based most logically upon advances and retreats of continental ice. The most universal expression of these volumetric variations is to be found in the evidence presented by changes in sea level. All oceanic surfaces were lowered as ice accumulated on the continents and were raised when melt-waters returned to the seas during times of glacial retreat. Study of the glacial record in the mid-continent region of the United States has revealed that five major ice advances occurred during that major part of Quaternary time known as the Pleistocene Epoch. Relatively mild and only partially glacial climates, thought to be similar to that which prevails at the present, characterized the intervals between glacial culminations. The beginning of the last ice retreat and the accompanying rise in sea level has been recognized as the event which initiated the Recent Epoch.

Although the area under consideration lies far south of the region that was covered by ice and far north of coastal regions inundated by glacially controlled seas, an accurate

Pleistocene record can be deciphered from its stream valleys. This is possible because the regimes of streams there were influenced by climates glacially imposed and ocean levels that varied according to existing volumes of ice. Draining to low sea positions during moist times of widespread glaciers, the streams carried large water volumes and flowed rapidly enough to erode their valleys. Between glacial periods water discharges were lowered when the seas rose to high positions on a continent that received little rainfall, and streams built up their valleys by deposition. The terraces in central and north-central Texas, formed on alluvium resting on ancient eroded valleys, were developed during recurring erosional and depositional episodes that attended multiple Pleistocene glaciation.

EFFECTS OF EXISTING RIVER REGIMES AND VALLEY GEOLOGY UPON THE BRAZOS AND WICHITA RIVERS

The modern flood plain of the Brazos and Wichita Rivers lies beneath the terraces and is the last in a series of Quaternary deposits. The study of floodplain development along the present streams, which appear to be in an alluvial habit similar to those of the Pleistocene, permits an insight into conditions that prevailed during times of Pleistocene sedimentation. Therefore, the behavior of both rivers has been investigated in detail.

The Brazos River

The Brazos River rises west of the Texas-New Mexico boundary and flows first in an easterly and then in a southeasterly direction toward the Gulf of Mexico, into which it drains. Its largest tributaries in the area studied are the Clear Fork, Paluxy, and Bosque Rivers.

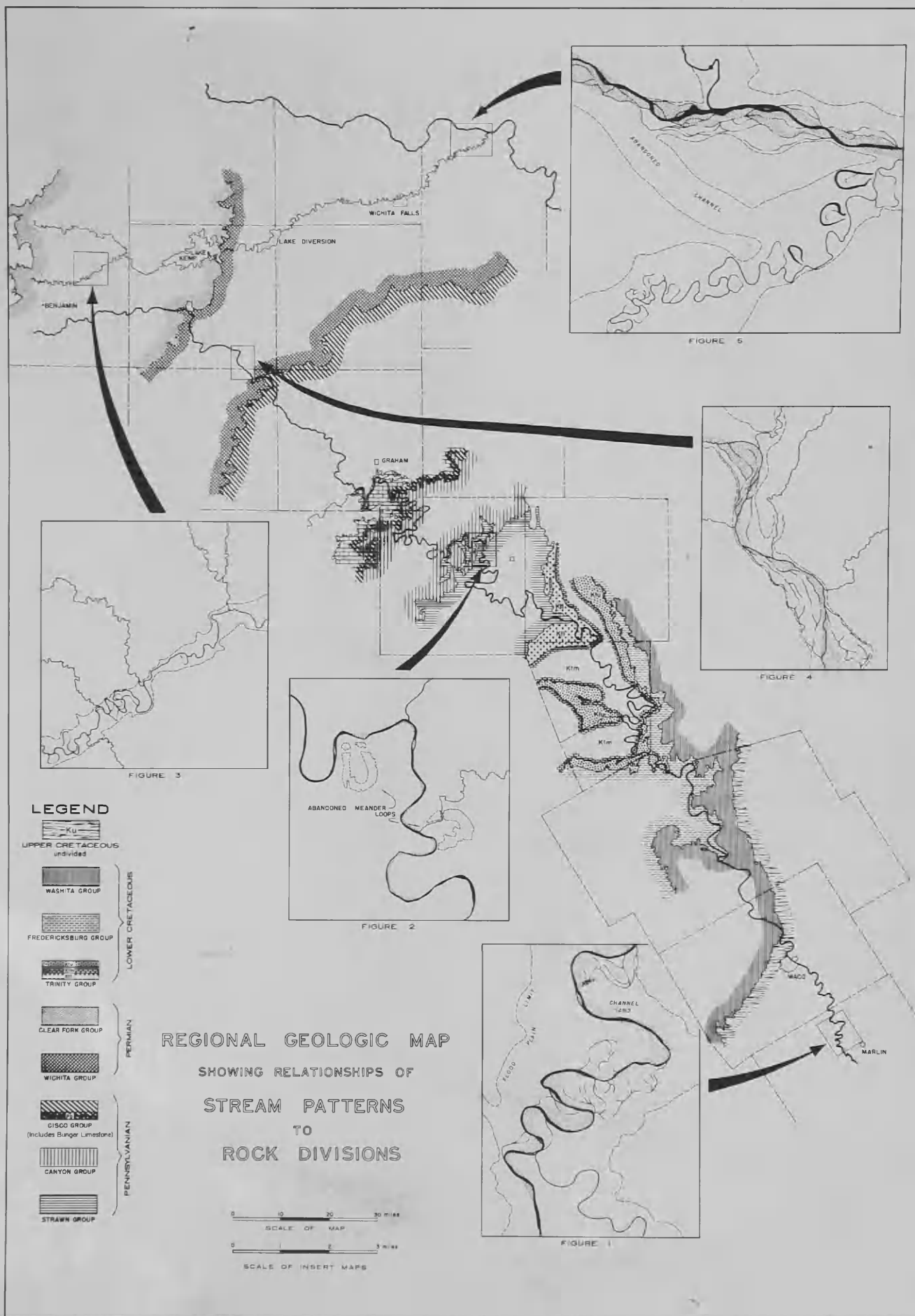
The examination of channel configurations along the river reveals three diverse stream patterns -- meandering, incised meandering, and braided. Each appears to be confined to outcrop areas of particular rock divisions which differ lithologically (pl. 1). Meandering patterns are developed in the alluvium that overlies unresistant marl and shale of Upper Cretaceous age. Incised meanders prevail in Lower Cretaceous and Pennsylvanian rocks comprised predominately

of resistant limestone and "redbed" strata that maintain steep valley walls during erosional incision. Braided patterns have been established in sandy Upper Pennsylvanian and Permian beds which are eroded very rapidly. Coincidence of each pattern with certain rock divisions reveals the key importance of lithology in controlling channel habit and appearance.

Meandering Patterns

G. H. Matthes (1941) defined a meandering pattern as: "any letter-S channel-pattern, fashioned in alluvial materials which is free to shift its location and adjust its shape as part of a migratory movement of the channel as a whole down the valley." Along meandering streams channel patterns change mainly during floods and falling flood stages when bank caving occurs most vigorously (Matthes, 1941). Sediments derived from bank caving are transported downstream and for the most part dropped as the water slackens over the next bar. The sediments active in meander development are mostly fine-grained and maintain relatively rigid banks which are destroyed chiefly by undercutting and collapse.

The conditions essential for meander development are large stage variations of the river, a supply of relatively fine-grained and easily eroded material along the bed and channel, and a relatively low gradient so that deposition may



occur where velocities are reduced. These conditions are present in the wide alluvial valley below Waco and explain the tendency of the stream there to meander vigorously (Pl. 1, Fig. 1). Low stage discharges of the Brazos River at Waco are commonly on the order of 1,000 to 5,000 cu. ft./sec., but during floods of the last fifty years, they have increased to as high as 246,000 cu. ft./sec. Both the alluvial flood plain and terrace sediments and the older marls and shales of the Taylor group are readily eroded. The gradient of the river there is 1.5 ft./mi., one similar to that of many other meandering streams.

Probably the most important factor supporting meander growth along this portion of the river is the nature of the bedrock. The meanders, absent upstream from Waco in resistant strata, begin in the first thick and unresistant sediments encountered, the Taylor shale.

Incised Meandering Patterns

Along the Brazos River between Waco and Graham the stream patterns are coarser and wholly unlike those caused by active meandering below Waco (Pl. 1, Fig. 2). The large bends, often angular and highly distorted, are not uniformly curved, and their diameters are not a function of stream volume, as is the case with active meanders. The river is confined to a narrow flood plain much more limited than the

swings exhibited by its pattern as shown on maps or visible from the air. The flood plain widens locally below slip-off slopes located along convex banks of the bends. The river flows over bedrock or a thin veneer of its own alluvium in a confined, steep-walled valley carved in resistant limestone and redbed strata. The term "incised meandering" may be used to describe the pattern presented by the river along this portion of its course, implying no connotation as to origin or development of the meanders. Both the river and its valley may be described as incised.

The incised patterns have developed in Pennsylvanian (Strawn, Canyon, and basal Cisco) and Lower Cretaceous (Trinity, Fredericksburg, and Washita) sediments. Most of these rocks are resistant and eroded with difficulty. Where less resistant sandstones of the Trinity group (Trinity and Paluxy) are exposed, excessive detritus is introduced into the river, and the floodplain alluvium increases in thickness and areal extent.

The stream gradient between Graham and Waco is 2 ft./mi. This is .5 ft./mi. steeper than below Waco and probably results from the presence of more resistant rocks exposed in the stream channel. The maximum discharges, which occur during the late spring and early summer months, often exceed 1,000 cu. ft./sec. and range up to 12,000 cu. ft./sec., the known maximum being 100,000 cu. ft./sec. The gradient

steepening occurs near Waco and coincides with the contact of the Austin-Taylor groups.

The growth of incised meanders is similar to that of active meanders. Evidence of enlargement of the incised meanders is offered by the extensive development of the flood plain and terraces in bends on slip-off slopes, the equivalent of the point bar of regular meanders. The stream channel is being directed laterally there by alluviation of the point bar and retreat of the bank opposite through undercutting and collapse. In Lower Cretaceous rocks the flood plain and terrace distribution in the bends indicates that the incised meanders are also migrating downstream. Bends in Pennsylvanian strata appear to have resulted from sidewise migration predominantly.

The growth of incised meanders is much slower than that of active meanders because of the resistant bedrock in which they are established and probably because of a greater restriction of development to periods of flooding. Active meander development in flood plains of the alluvial valley below Waco takes place during much of the time but is accelerated during floods. On the other hand, incised meanders grow chiefly only when high waters effectively erode resistant bed and channel rocks.

Incised meanders are more permanent than active meanders because of the resistant nature of the rock in which

they develop. Cut-offs are rare but well-preserved (pl. 1, Fig. 2).

Braided Patterns

Between Graham and Benjamin, Knox County, braided patterns are prominent along the river where sandy Upper Pennsylvanian (Cisco) and Permian (Wichita and Clear Fork) strata are exposed (Pl. 1, Fig. 4). Development of this pattern appears to result from rapid erosion of beds and banks and almost immediate deposition of coarse materials. Vigorous bank undercutting is aided by a steep channel gradient of about 3.1 ft./mi. Bank collapse obstructs channels so that they are shifted to new positions. Incohesive bed and bank materials respond so actively to erosion that they do not seem capable of maintaining a meandering stream channel. Most rapid introduction of load into the streams takes place during floods; between them during dry periods shallow flows spread about over wide, flat flood plains in anastomosing, braided patterns.

The Wichita River

The Wichita River rises on the breaks of High Plains and flows toward the east into the Red River near Wichita Falls. It receives considerable tributary flow from the South Wichita River near the Baylor-Knox county line (Fig. 1).

Courses of both the master stream and its large tributary are confined to regions of exposure of Permian strata which are comprised predominantly of poorly cemented sandstone and siltstone. The only resistant beds that are exposed along either stream crop out along Wichita River between Lake Kemp and Lake Diversion.

Along the Wichita River meandering patterns predominate and occur below Lake Diversion where the river flows in an alluvial valley all the way to its confluence with the Red River. Meanders are well-developed there on a wide flood plain (Pl. 1, Fig. 5). The excellent braided patterns that occur along the Red River in this vicinity probably result from a steep gradient, one of 3 ft./mi., as compared with 1.3 ft./mi. for the Wichita River in its alluvial valley.

Above Lake Diversion the river, sloping at about 2.3 ft./mi., is confined in an incised valley carved in rocks of the upper Wichita group. The steep channel walls of the incised meanders are there maintained by Lake Kemp and Mabelle limestones.

Above Lake Kemp braided and meandering patterns occur along both the North Wichita and South Wichita River. In Knox County the South Wichita River meanders are developed along a gradient of about 3 ft./mi. Here the river cuts sandy Clear Fork strata beneath a very thin cover of flood-plain alluvium. The braided patterns are confined to an

interval of steepened gradient between Lake Kemp and the
Baylor-Knox county line.

PROPOSED TERRACE TERMINOLOGY

Four new names are to be applied to the terraces recognized in this study. The type area for the three youngest of these is within Lofers Bend quadrangle of the Brazos River Commission and Reclamation District, prepared by the Brazos River Commission in 1937-38. These quadrangles, contoured on a ten-foot interval at a scale of one inch to 1,000 feet, accurately illustrate the terrace surfaces and associated scarps. Borings by the Corps of Engineers, U. S. Army, for the Whitney dam site, 6-1/2 miles southwest of Whitney, western Hill County, penetrated the terraces along several lines of section, and have provided additional stratigraphic control. The type area of the oldest terrace is approximately 16 miles southeast of the Whitney dam site, one mile from West, a town in northern McLennan County. This fourth terrace is almost completely removed by dissection and occurs at only a few isolated localities along the middle Brazos River. The lack of strategically located geographic place names led to the selection of land survey division names for terraces in all but one instance.

Lofers Terrace

The youngest Pleistocene surface, Lofers terrace, is named for Lofers Bend, an incised meander loop along the

Bosque-Hill county line. Lying at an elevation of 485 feet, it is present both above and below the dam, occurring immediately east of and slightly higher than the flood plain (Pl. 2). Developed there only on the left bank of the river, it is extensive in the bend and narrows in the vicinity of the spillway.

Mixon Terrace

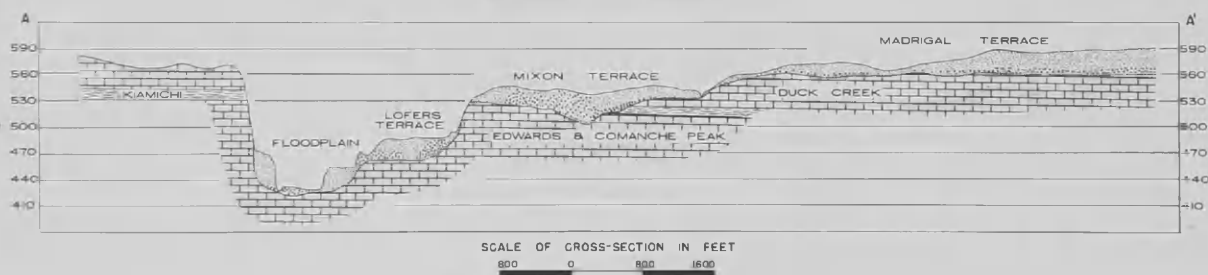
The next older surface, Mixon terrace, is named for a surface developed on Mixon land survey in the Whitney Dam area. It lies immediately east of Lofers terrace, separated from it by a 60-foot westward facing scarp, at an elevation of 545 feet (Pl. 2). Because of the resistant Edwards limestone that underlies the terrace deposits, Mixon scarp is especially well preserved.

Madrigal Terrace

The next oldest Pleistocene surface, Madrigal terrace, occurs on Madrigal land survey east of Whitney, Hill County. Being more highly dissected than the younger terraces, it varies from 570 to 610 feet in elevation. Its scarp has been modified and has not retained the angularity characteristic of those of younger terraces.



SCALE OF MAP IN FEET
1600 0 1600 3200



SCALE OF CROSS-SECTION IN FEET
800 0 800 1600

MODIFIED FROM CORPS OF ENGINEERS GEOLOGIC SECTION

PLATE 2

PLEISTOCENE TERRACES ALONG BRAZOS RIVER NEAR WHITNEY DAM, HILL COUNTY

Gerik Terrace

The oldest Pleistocene surface, Gerik terrace, occurs about one mile southwest of West, McLennan County, about one-half mile from U. S. Highway 77 and 81. This highest terrace is present at only a few localities along the Brazos River above Waco, but is well developed along the lower river (Cox, 1949). Its sediments have been dissected by prolonged erosion and consist predominantly of coarse gravel lying at an elevation of about 630 feet.

THE PLEISTOCENE TERRACES

Identification of the terraces involves recognition of gently sloping depositional surfaces in varying stages of erosional modification, the oldest being the most intensely dissected. The terraces are terminated toward lower surfaces by scarps on which bedrock usually crops out below the unconsolidated sand, silt, and gravel. Comprised predominantly of loose sand and silt and waterworn gravel in basal portions, terrace deposits are deep red in color and usually cross-bedded. Gravels are their most conspicuous lithologic element and, offering more resistance to erosion than the other constituents, they often are the only remaining residues of a terrace deposit that formerly extended widely.

Comparatively rich soils develop in the finer alluvium of terrace flats. In areas of abundant rainfall aquiferous alluvium provides water for a flora comprised characteristically of pine and oak trees and prairie grasses. In north-central Texas, a somewhat drier region, sparse vegetation consists of mesquite bushes and hardy prairie grasses.

Mapping Methods

The terraces were mapped on aerial photograph mosaics. Terrace boundaries established by field profiles were extended beyond the control of the road network by interpreting

topographic and lithologic features seen on mosaics and other available maps. Topographic quadrangles, contoured on an interval of ten feet, by the Brazos River Commission and Reclamation District, provided excellent control for areas adjacent to the Brazos River between Graham and Whitney.

Unmodified Surfaces

Mapping of the younger terraces, which are generally quite fresh, involves the identification of scarps, shown on aerial photographs by characteristic tone contrasts and drainage patterns. Because of heavier vegetation and shadowed slopes, scarps are shown as dark bands. In agricultural areas where scarps have not been cleared, their appearance contrasts vividly with that of the cultivated surfaces. If both have been cleared and plowed, scarps are generally revealed by agricultural terraces that resemble contours on a topographic map.

Streams draining scarps have characteristic patterns. Short, straight drains normally enter a large stream which tends to run close to the base of a scarp. Incision of this stream into bedrock that crops out along the bottom of the scarp produces distinct drainage patterns, usually sharply etched and dendritic. Because of the consolidated nature of the bedrock, the channel walls remain steep during erosional incision. The short drains that enter this stream are usually

terminated by gullies in terrace deposits at the top of the slope. In unconsolidated alluvium there the pattern of the gullies is indistinct because their walls slope gently.

The surfaces of the younger terraces occasionally display pimple mounds, remnants of initial drainage divides of low relief, and channel scars. The former, because of their hummocky nature, appear on photographs as rounded spots (Pl. 3, Fig. 3).

Dissected Surfaces

In some areas the older terraces have been so highly dissected that neither their scarps nor former surfaces are recognizable. All occurrences of Gerik terrace, and some of Madrigal, are of this nature. The correlation of isolated remnants is ordinarily positive enough because elevations between the four levels in the region are spaced by intervals of from 40 to 60 feet, and in areas adequately controlled by profiles, few cases of possible confusion were encountered. In such instances the mapping of terrace remnants involved identification of lithologic types indicated mainly by weathering phenomena shown on the photographs. A stratigraphic familiarity with the older sediments aided immensely in mapping the Pleistocene outliers.

Limestones are indicated by very dark shades resulting from the dense growth of cedars. The dissection of thick

EXPLANATION OF PLATE 3

Figure 1 - Dissected, light-colored Lofers (Qt1) and Nixon (Qtmi) alluvium resting on Taylor (Kta) shale in McLennan County. The road trending from the southwest intersects Texas Highway 434 on the east at Downsville, 5-1/2 miles southeast of Waco.

Figure 2 - Alluvium overlying Glen Rose (Kgl) limestone in Somervell County. In the lower-center portion of the figure, Texas Highway 144 intersects Squaw Creek about three miles northeast of Glen Rose. Floodplain alluvium along the creek, Lofers (Qt1), and Nixon (Qtmi) sediments contrast vividly with heavily vegetated, distinctly bedded Glen Rose limestone. Paluxy (Kpa) sand overlies Glen Rose strata to the southwest.

Figure 3 - Madrigal (Qtma) and Nixon (Qtmi) terrace surfaces contrasting with dendritically drained Permian (Cpm) Clear Fork sandstone in Knox County. In the top-center of the figure, Texas Highway 267 intersects U. S. Highway 82 about 3-1/2 miles north of the Brazos River. White Pearlette (Qtpe) ash crops out on Madrigal scarp.

Figure 4 - Lofers (Qt1) alluvium resting on massive, heavily vegetated Edwards (Ked) limestone in Hill County. The easternmost portion of the river is about 3-1/2 miles due west of Blum. Kiamichi shale and Fort Worth limestone, lower divisions of the Georgetown (Kge) limestone, overlie Edwards strata to the east. Low hills formed on Georgetown beds reflect light in a peculiar manner.



FIGURE 1



FIGURE 2

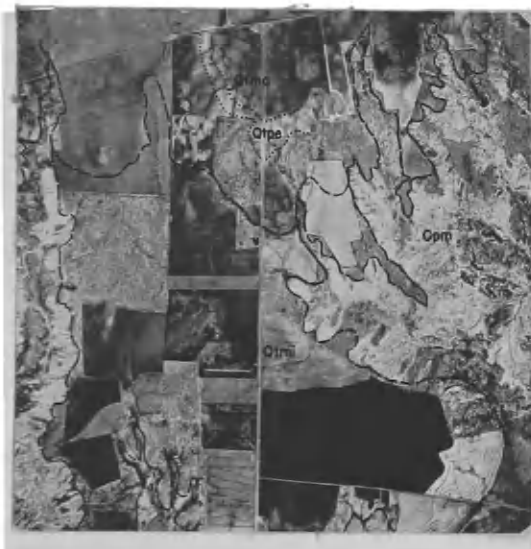


FIGURE 3



FIGURE 4

Scale - One inch equals one mile
 North is at top-center of each figure

PLATE 3

LITHOLOGIC INTERPRETATION OF AERIAL PHOTOGRAPHS

limestone such as the Glen Rose and Edwards has produced flat divides bounded by steep slopes on which bedding planes are often traceable (Pl. 3, Figs. 2 and 4). Lines of cedars, particularly dense on certain beds, appear as contours on some slopes. Fresh, unvegetated limestone is shown by light shades.

The weathering of Cretaceous marls and shales on divides produces uniformly rounded, regularly spaced hills shown on photographs as dark areas flecked with lighter spots. The Walnut, Kiamichi and most of the other formations in the Washita group, Eagleford, and Taylor strata present this appearance if weathered (Pl. 3, Fig. 4). In flat areas black soils that develop on these deposits are shown by very dark shades.

Weathered sandstones and conglomerates such as the Paluxy, Trinity, Strawn, and Cisco are very easily confused with terrace deposits. Where older deposits of this nature are deeply dissected, steep slopes and rugged topography characterize their outcrops. In regions of low relief infertile soils that support sparse vegetation cover their outcrops, contrasting with the densely vegetated soil typical of terrace alluvium. In regions where terrace and bedrock deposits do not contrast, mapping demands additional and more detailed work in the field.

Distribution

This investigation has revealed the occurrence of four terraces along the Brazos River and two along the Wichita River. Arranged step-like above the flood plain, each trends down valleys, not everywhere, but at a sufficient number of places to justify correlation from remnant to remnant along the valley walls. The two terraces along the Wichita River correlate with the two youngest surfaces, Lofers and Nixon, along the Brazos River, each lying at comparable heights above both streams. Older terraces, reduced in extent along the Brazos River by erosion, are absent along the Wichita River probably because it is a younger stream--one not existing during the earlier part of the Pleistocene.

Alluvial Valleys

Both flood plains and terraces broaden notably downstream along the Brazos and the Wichita Rivers. Along the southern Brazos River the terraces change from fluvial valley strips representing old flood plains into coastwise belts which were the alluvial coastal plains flanking the Gulf of Mexico during various Pleistocene stages (Fig. 2). Portions of these coastwise terraces have been mapped in Louisiana and Texas by Fisk, Holland, Welch, Bernard, Cox, and others. Just as the present deltaic coastal plains with their marshes

and swamps pass without interruption into the river flood plains inland, the deltaic coastal plains of the Pleistocene correlate directly with the fluvial terraces inland.

The coastwise terrace deposits pass from higher positions according to greater age inland to a normal stratigraphic sequence gulfward, so that the oldest deposits lie at the base of the Pleistocene section. Subsidence arising from geosynclinal deposition has buried equivalents of terrace deposits beneath sinking deltas and downwarped the landward surfaces of the coastwise terraces, the oldest being tilted the greatest amount. Farther inland along their fluvial parts, gradients of all the terraces become essentially parallel, their heights above the stream decreasing only slightly in an upstream direction. In the alluvial valley of the Brazos River near Waco, the three terraces present are separated by vertical intervals of 45 to 50 feet, lying at heights of 105, 150, and 200 feet above the channel (Pl. 4). The oldest terrace, Gerik, is not present in the modern alluvial valley in this region, but its equivalent is extensive to the south along lower Brazos River. In the alluvial valley of the Wichita River the two terraces present lie 45 to 80 feet and 120 to 150 feet above the channel (Pl. 8). These values are similar to those of the two equivalent surfaces, Lofers and Nixon, along the Brazos River, the lowest along the Wichita River being more variable and occurring at

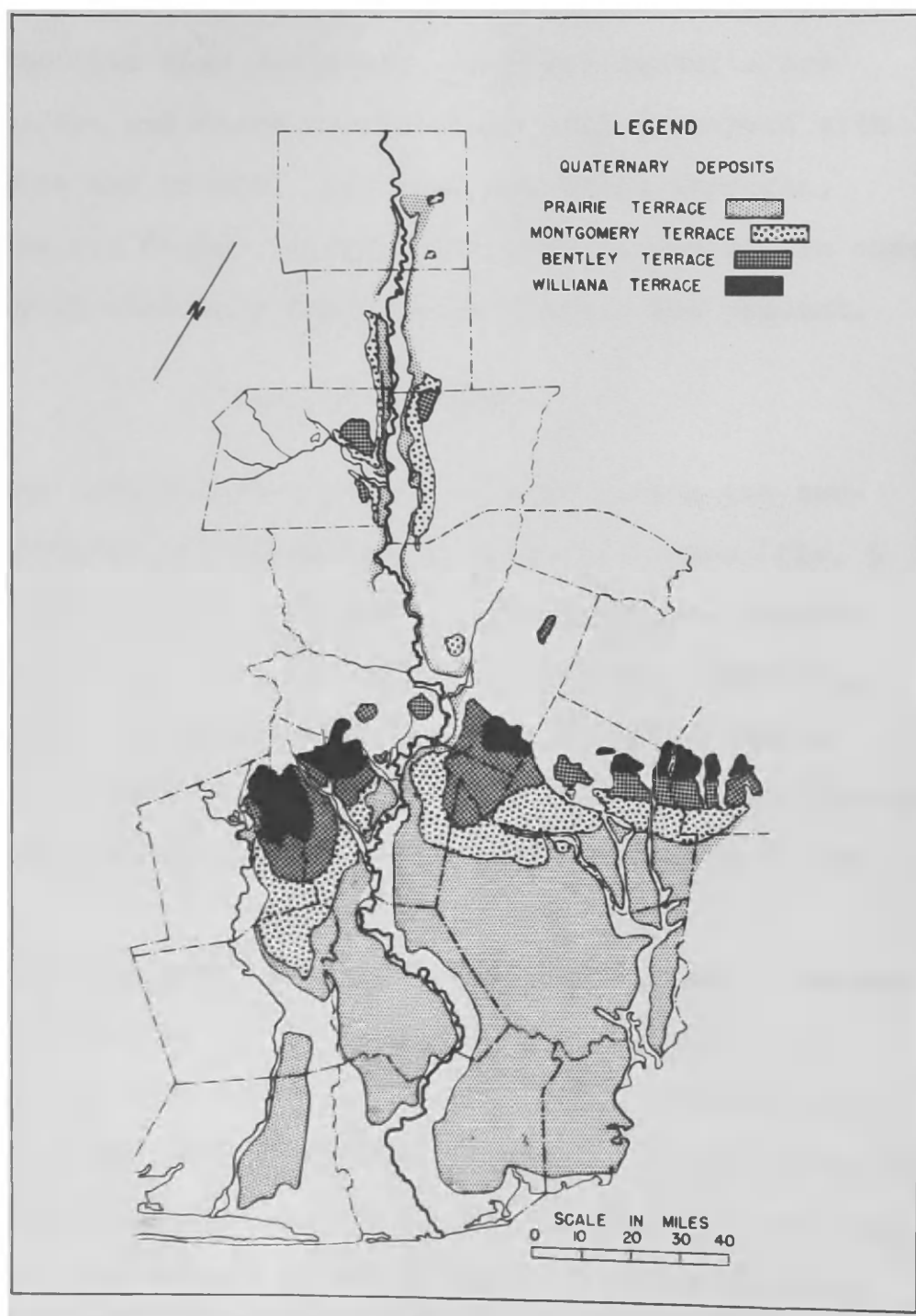


Figure 2 - Fluvial and coastwise terraces along the lower Brazos River. After Cox.

lesser heights.

In the alluvial valleys of both rivers the terraces are more extensive than upstream, and their deposits are thicker. Lofers and Nixon terraces are well preserved with fresh surfaces and scarps. Madrigal and Gerik terraces, restricted to the Brazos valley, have been dissected, in some cases so highly that only their basal gravels are present.

Incised Valleys

Along the incised portions of both rivers the terraces are confined predominantly to slip-off slopes (Pls. 5 and 7). Along straight stretches of the river, or reaches, the terraces, if present, are extremely narrow. Only one, Lofers, is known to be present along the incised Wichita River, between Lakes Kemp and Diversion. All four are present in the incised valley of the Brazos River between Waco and Graham.

Near Graham the terraces lie at their lowest observed heights, occurring at 40, 90, 150, and 190 feet above the channel (Pl. 5). The vertical intervals that separate them vary from 40 to 60 feet, comparing with those of the alluvial valley, but the surfaces are appreciably lower along the incised stream. The height of Gerik terrace, 270 feet above the river in northern McLennan County, decreases to below 200 feet in the upper incised valley, the northern limits of

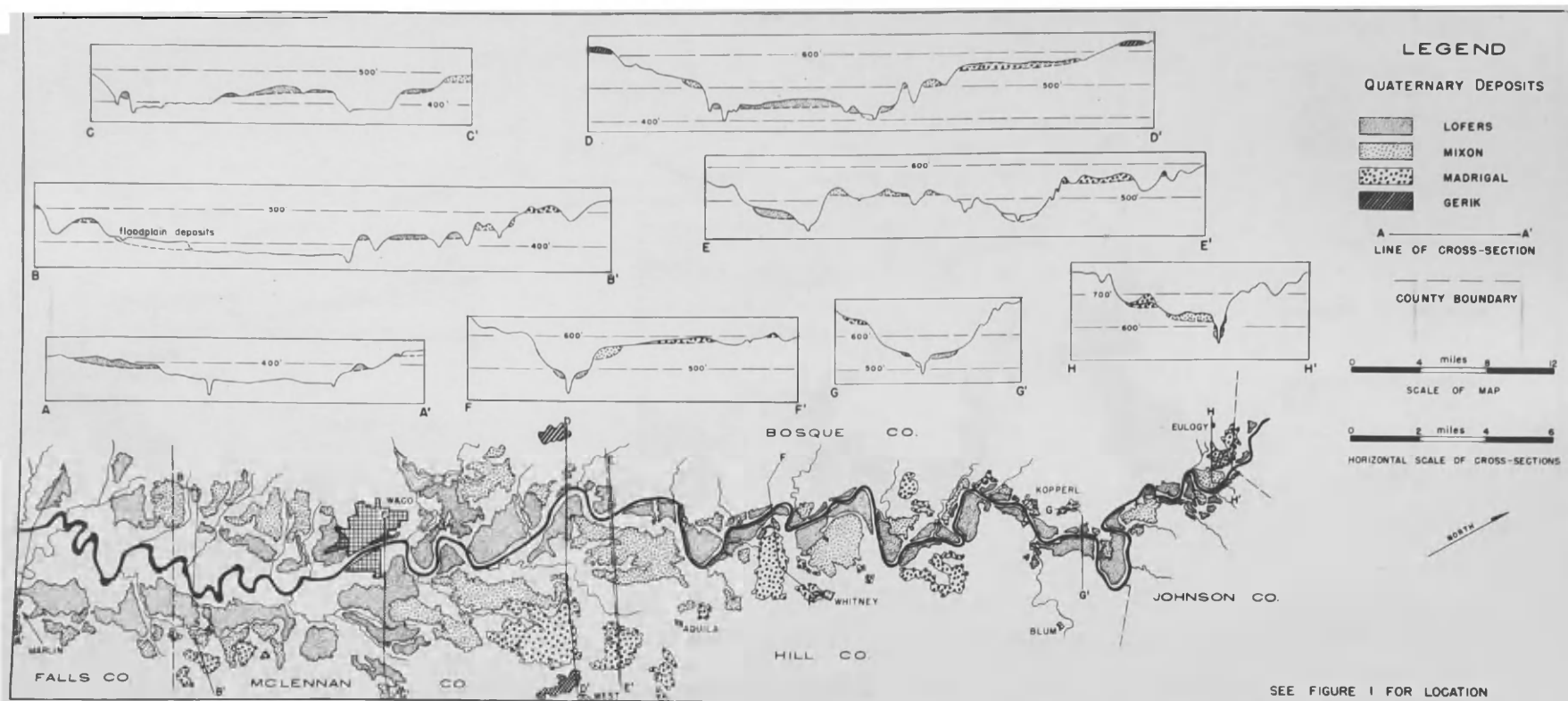


PLATE 4
BRAZOS RIVER TERRACES

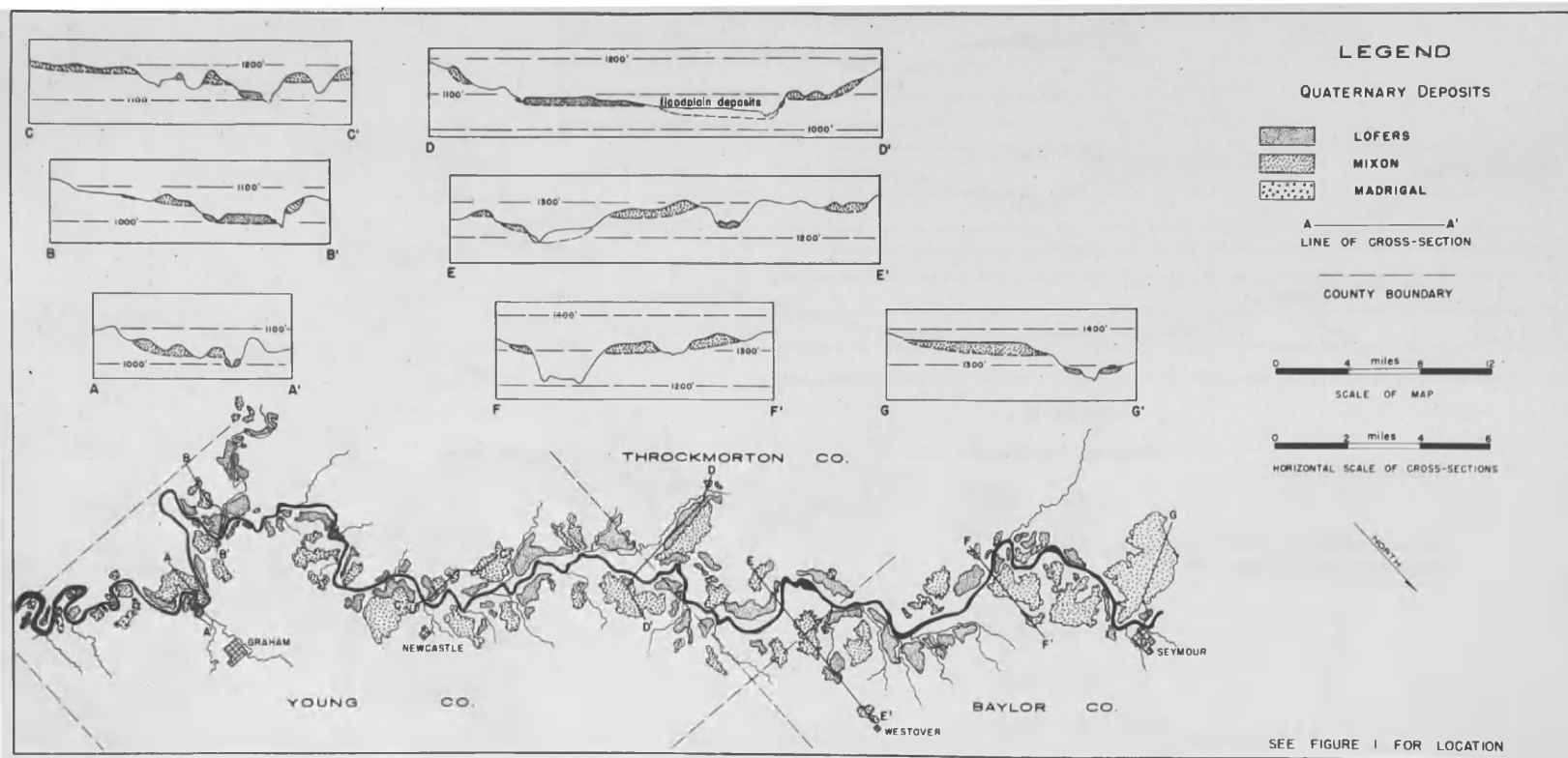


PLATE 6
BRAZOS RIVER TERRACES

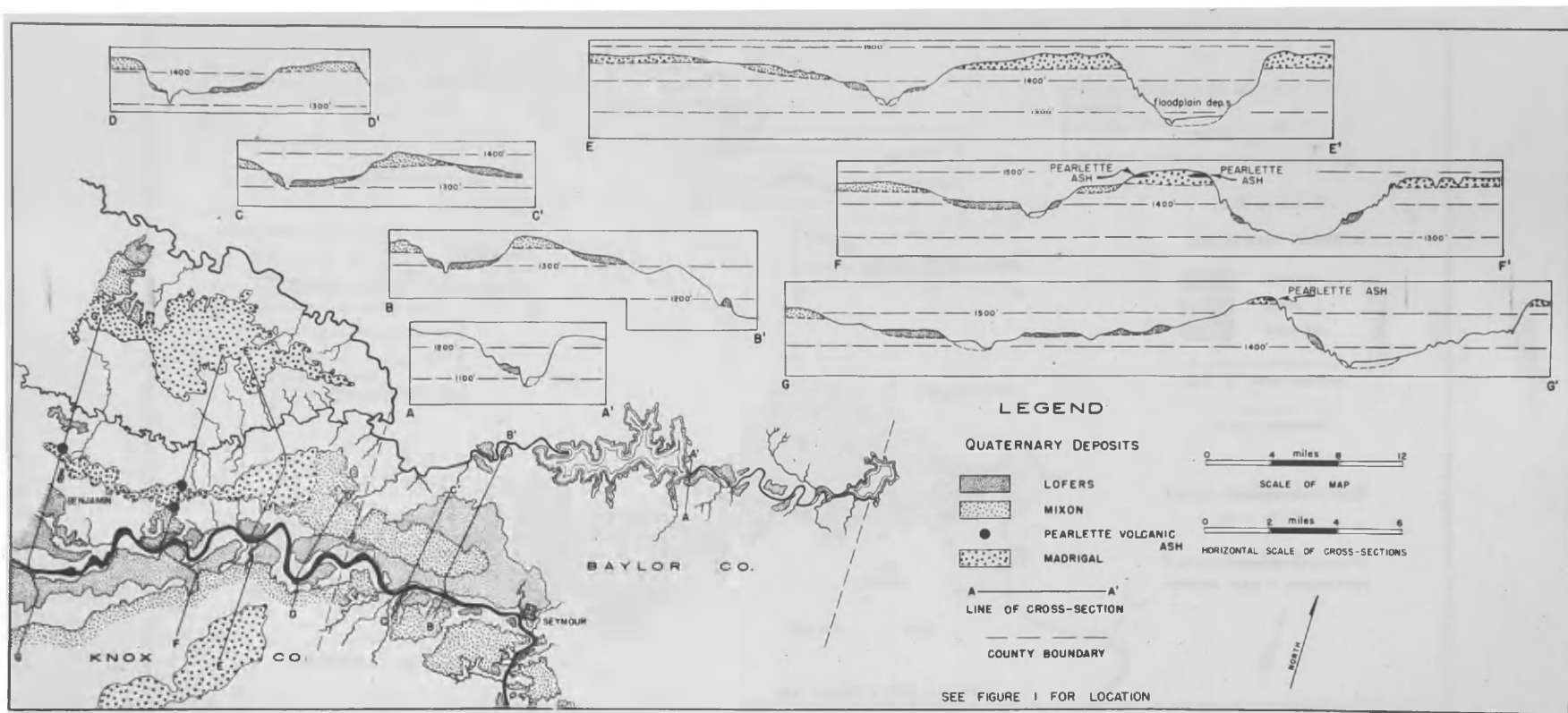


PLATE 7
BRAZOS AND WICHITA RIVER TERRACES

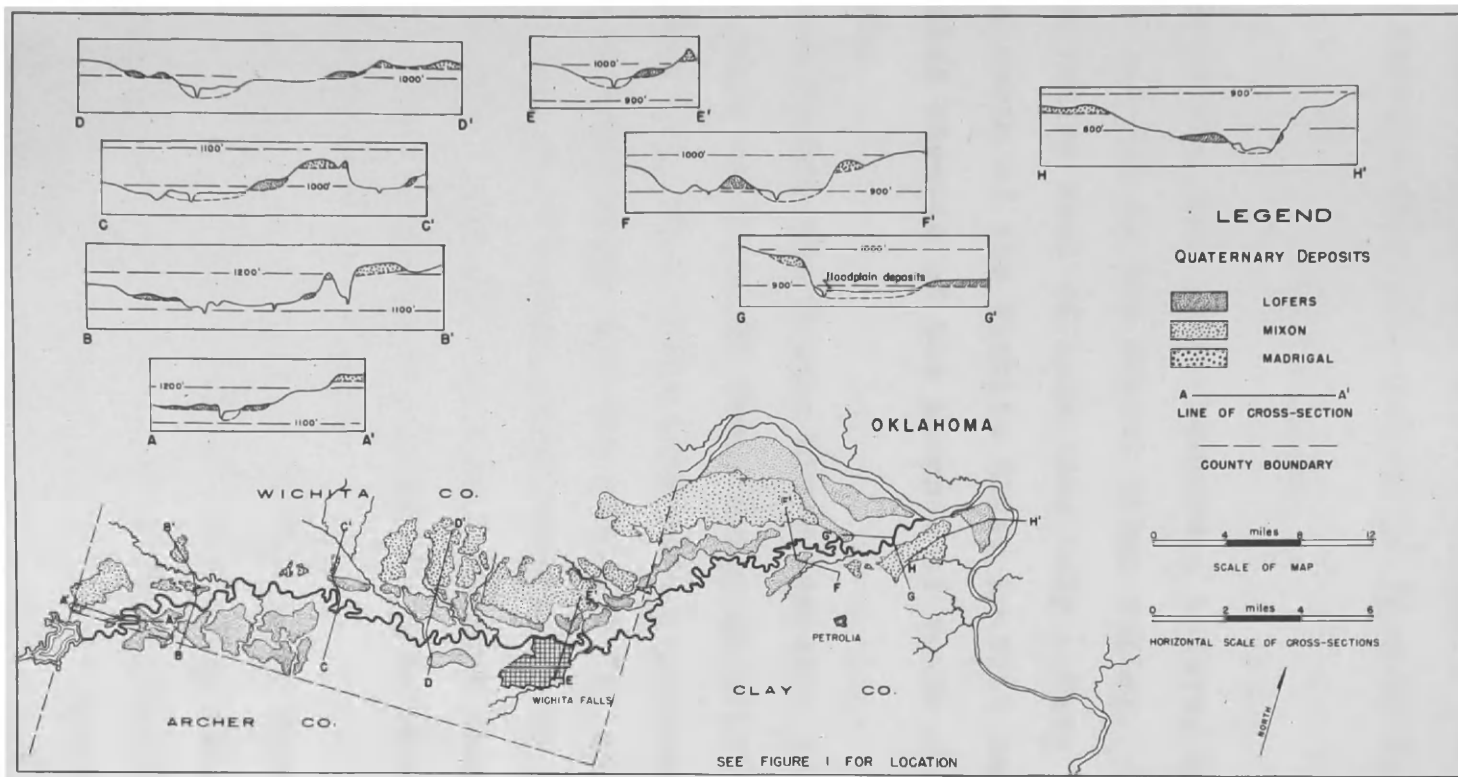


PLATE 8
WICHITA RIVER TERRACES

its occurrence.

Near Lake Kemp in the incised valley of the Wichita River Lofers terrace lies at a height of from 60 to 70 feet.

Upper Valleys

Above Graham only three terraces, Lofers, Nixon, and Madrigal, are present in the Brazos River valley. In the Wichita River valley west of Lake Kemp only Lofers terrace is known. Areas north of the Wichita River in this region were not investigated because of the absence of roads on the Waggoner Ranch.

In Knox County the Brazos River terraces are separated by intervals of 50 to 60 feet, lying at heights of 50, 110 and 160 feet (Pl. 7). These intervals of separation compare with those downstream, but the surfaces lie at slightly greater heights than at Graham, each increasing by about 10 feet up the valley. Madrigal terrace is absent along the upper valley between Graham and Seymour but reappears in excellent development in Knox County.

Only Lofers terrace occurs in the upper Wichita River valley (Pl. 7). Older terraces have been mapped on the divides in the Upper Wichita system but their distribution suggests a genetic relationship to the Brazos River, indicating that the part of Wichita River west of the Baylor-Knox county line was formerly tributary to the Brazos River.

Other evidences indicating this relationship will be cited later.

Madrigal terrace in Knox County is more widely developed than younger Lofers and Nixon surfaces, its unusually well preserved surface forming flat drainage divides between the Brazos, North Wichita, and South Wichita Rivers (Pl. 7). This region lies within a belt of extensive Pleistocene deposits that occur in Texas, Oklahoma, and Kansas, their exposures trending parallel to the border of the High Plains (Fig. 3). These sediments, both eolian and fluvial, overlie Permian sandstone. In north-central Texas large gravels that occur in Madrigal deposits have probably been derived from older gravilliferous beds (Ogallala?) that cap the High Plains. The exceptional preservation of Madrigal terrace in this area probably results from its large quantities of gravel, which are removed with difficulty, and its greater than average thickness, which may be as much as 60 feet. Both factors indicate abnormal deposition in this area during Madrigal time.

Longitudinal Profiles

Longitudinal valley profiles of each surface have been constructed by plotting their elevations on profiles of the Brazos and Wichita Rivers surveyed by the U. S. Corps of Engineers (Pl. 9). Elevations used to plot the terrace

surfaces were established by running numerous profiles across the valleys, usually across bridges where control was offered by stream profiles. Actually the terrace profiles are reconstructions of floodplain slopes that existed during times of Lofers, Nixon, Madrigal, and Gerik deposition. The four profiles, almost parallel along the Brazos River, indicate that no very pronounced modifications of stream gradient occurred during the Pleistocene (Pl. 9, Fig. 1). The profiles of Madrigal and Gerik terraces are not continuous because those surfaces are absent along considerable stretches of the river.

Only two terraces, Lofers and Nixon, occur in the valley of the Wichita River, and their profiles roughly parallel the stream channel like those of the Brazos River (Pl. 9, Fig. 2). Above Lake Kemp Dam terraces on divides overlooking the Wichita River and its forked branches, the North and South Wichita Rivers, appear to be genetically associated with the Brazos River to the south, profiles of their surfaces sloping at about the same rate as those of the larger stream. This and other evidence offered in an abandoned valley leading to the Brazos River suggests that the ancestor of the upper Wichita River was diverted from the larger to the smaller stream, the diversion occurring just below the present fork of the North and South Wichita Rivers. Since the drainage change, because of increased

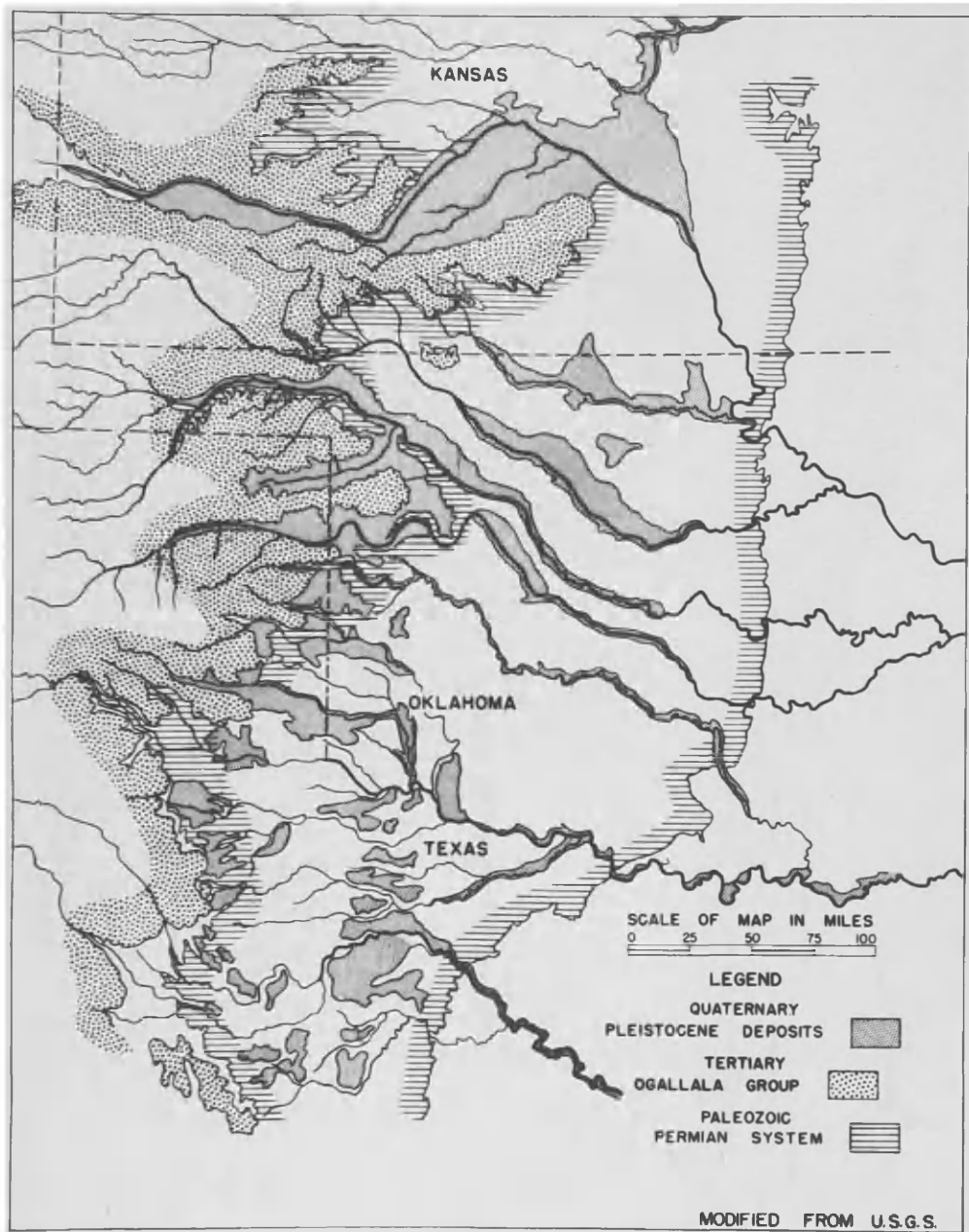


Figure 3 - Regional outcrop map of Pleistocene deposits showing their relationship to older, graveliferous sediments (Ogallala) that cap the High Plains.

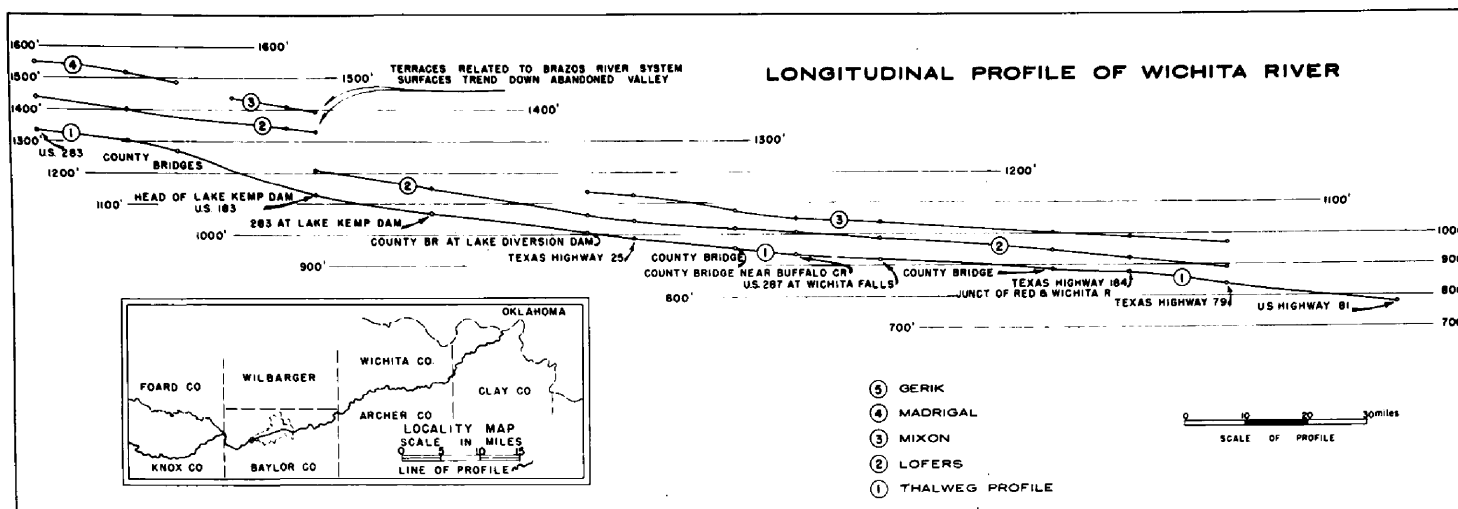


FIGURE 2

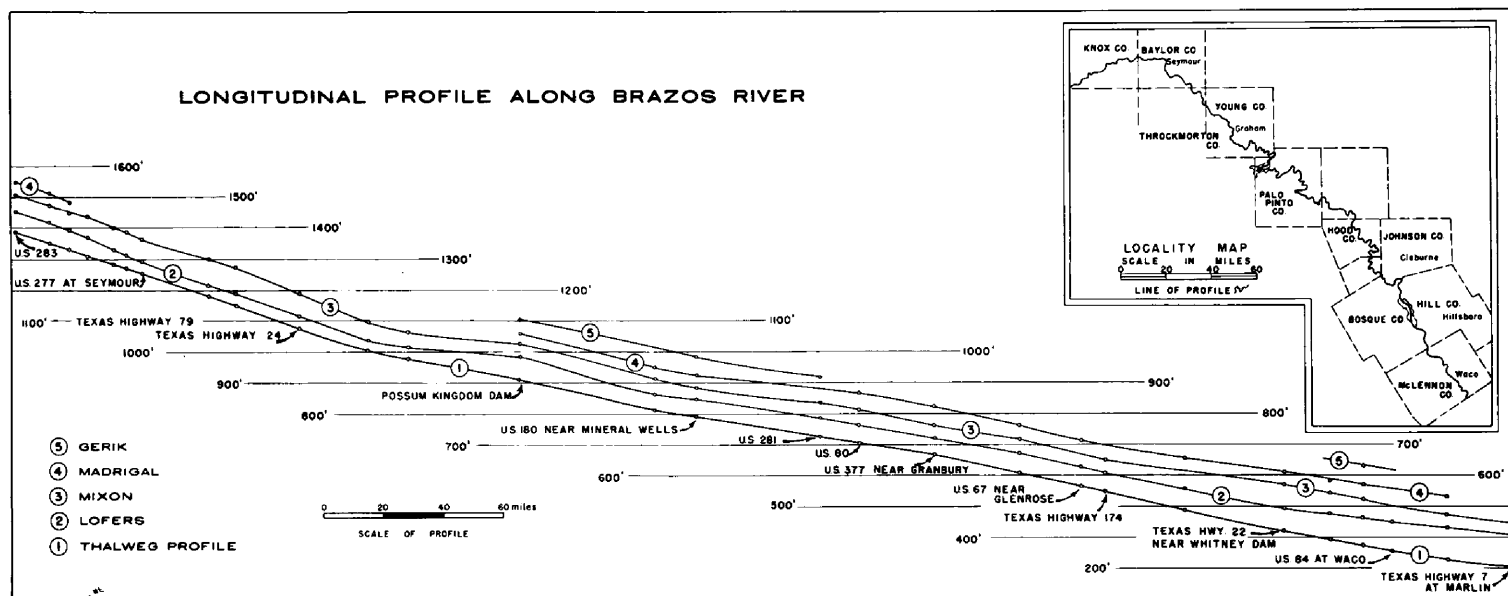


FIGURE 1

PLATE 9
BRAZOS AND WICHITA RIVER PROFILES

gradient at the site of the diversion, the channel of the former tributary has been lowered and steepened, the greatest amount of both occurring immediately above the diversion point. Because of the local channel lowering, the terraces stand at greater heights above the stream (Pl. 9, Fig. 2). The surfaces extend away from there down the abandoned valley.

Lithology

The Pleistocene terraces, like the flood plains at lower positions in the valleys, are developed on alluvia containing considerable quantities of gravel in their lower sections, the upper fine-grained sediments having only scattered amounts. Thicknesses of the terrace deposits average around 30 feet and range up to 60 feet.

Where the terrace deposits have been highly dissected, as along scarps, abundant basal gravels may be seen, overlying bedrock if the dissection has penetrated deeply. Erosion and removal of the upper fine-grained sediments from Madrigal and Gerik terraces have left only gravel scattered widely over some regions. Being the last of the terrace constituents exposed and the most difficult to remove, the basal gravels often cap hills and divides, presenting the only evidence of deposits that formerly blanketed the area.

The gravels, worn by stream action to sub-rounded and



rounded shapes, are generally uncemented and consist predominantly of chert, quartzite, quartz, and minor amounts of petrified wood and silicified Cretaceous fossils. Their average sizes are about one inch for the younger alluvia and slightly greater than that for older Madrigal and Gerik deposits where six-inch pebbles are known to occur.

The bulk of the terrace sediments consists of cross-bedded, lenticular bodies of sand and silt, with minor amounts of clay. Oxidation of these constituents has imparted a characteristic deep red color to the deposits of all terraces in the area studied. The sand grains consist mostly of quartz, rounded to various degrees and "frosted" where they have been derived from Permian deposits eroded in north-central Texas. Greater amounts of sand occur in terrace sediments around the confluence of the Wichita and Red Rivers, probably as a result of deposition by the Red River which transports sand primarily.

A volcanic ash facies (Pl. 10 and Pl. 7, Sec. E-E', F-F', Fig. 3) associated with the upper sediments of Madrigal terrace in Knox County provides a very important correlation datum for establishing the glacial chronology of the terraces. Similar deposits of ash, Pearlette, reported by Frye, Swineford, and Leonard (1948) and determined to be associated with Yarmouthian interglacial deposits, are known from numerous widely separated localities in the Great Plains.

Swineford examined a sample of ash from Madrigal deposits in Knox County and reported:

The glass is relatively unweathered and has a refractive index of $1.499 \pm .002$. The shards are strongly curved with thickened bubble junctures at high angles; all these features are typical of Pearlette ash.

Three separate localities of ash occurrence are known in Knox County, all north of the Brazos River and within eight miles of Benjamin (Pl. 7). It occurs as lenses three to seven feet thick in Madrigal deposits. Two outcrops are near the junction of U. S. Highway 82 and Texas Farm Road 267, one located three-fourths to one mile north of it along Texas Farm Road 267 (Pl. 10), the other located about the same distance south of it along Texas Farm Road 267. In both places ash occurs in the road cut and in outcrops on both sides of the highway. A third ash locality is along Texas Highway 283, about two miles north of its junction with U. S. Highway 82 at Benjamin, approximately 100 yards east of the road near the top of a high scarp that fronts the Wichita River valley.

In all three localities the ash lies conformably above a bed of grey or brown clay about eight feet thick. In the two localities north of U. S. Highway 82 a considerable thickness, about 20 feet, of cross-bedded Madrigal silt, sand, and gravel underlies the clay and rests on evenly bedded Permian sandstone. The persistent occurrence of clay



Figure 1 - Ash in Pleistocene Outlier

View is northeast from Texas Highway 267, one mile north of its junction with U. S. Highway 82, Knox County. This Madrigal terrace remnant is adjacent to an erosional scarp that marks the southern limit of South Wichita River valley. Silt and caliche overlie a resistant ledge developed on the ash. An underlying clay bed separates the ash from a section of sand and gravel which is about 20 feet thick. Gullied Clear Fork sandstone underlies the Pleistocene deposits.



Figure 2 - Ash Resting on Madrigal Alluvium

Exposure 50 feet west of Texas Highway 267, three-fourths mile north of its junction with U. S. Highway 82, Knox County. Beneath the light-colored ash, sand and gravel underlie seven feet of clay.

PLATE 10

EXPOSURES OF PEARLETTE ASH

beneath ash in all three localities suggests that the ash was dropped on flood plains that existed during Madrigal deposition and reworked by the wind, accumulating as pockets in swales and buried by later alluviation. The surface of the terrace is developed on silt, containing large amounts of caliche, that overlies the ash.

Stratigraphic Nomenclature

Each terrace is developed on deposits that have been differentiated and mapped in the stream valleys of the area under investigation. Because they are distinct lithologic units that can be mapped conveniently over wide areas, it is herein proposed that the deposits of each terrace be given formational rank and bear the same names applied to the terraces. It has been earlier recommended that the terms Lofers terrace, Nixon terrace, Madrigal terrace, and Gerik terrace be used to indicate topographic surfaces. It is further proposed that these same terms be retained and applied in a formational sense to the lithologic units on which the topographic surfaces are developed. Type localities of the Lofers, Nixon, Madrigal, and Gerik formations are considered to be the same as those established for the terraces.

DRAINAGE REALIGNMENTS

Old stream courses abandoned during Recent and Pleistocene time may be noted on aerial photographs by the configuration of alluvial surfaces and relict drainage patterns. Former channels are best preserved on the lower surfaces, especially the flood plain, where they have been less altered by erosion.

Recent

Scars left by neck and chute meander cutoffs are very common on the flood plains in the alluvial valleys of both rivers. Those of neck cutoffs, when sealed at the ends, often contain "oxbow lakes." Chute cutoffs produce only slight modifications of meander loops, and their alteration gives rise to the accretion topography, alternating bars and swales, characteristic of point bars.

Evidences of larger drainage changes are less numerous. A diversion of the Red River to the north, near its confluence with the Wichita River, has left a considerable portion of its former flood plain abandoned. The Wichita River, lengthened by about four miles by this re-alignment, now flows over part of the old flood plain.

Near Marlin, in Falls County, a former course of the Brazos River, now occupied by Cow Creek, was abandoned when

the stream shifted to the western side of its flood plain. The smaller underfit stream follows old meanders obviously related to the Brazos River because of their large size.

Pleistocene

The detection of courses formerly occupied by Pleistocene streams is more difficult because old scars have been more highly altered by erosion. Two neck cutoff scars occur in the valley of the incised Brazos River, about six miles northwest of Mineral Wells, Palo Pinto County (Pl. 1, Fig. 2). Both of the old courses lie on abandoned Pleistocene surfaces, one on Lofers and the other on Madrigal. The necks, incised deeply into Pennsylvanian strata of the Canyon groups, have been well preserved by resistant rocks that maintain their steep walls. The occurrence of only these two former loops in the incised valley has led to the conclusion that few neck cutoffs have occurred there.

Seymour Diversion

Northwest of Seymour on a relatively flat drainage divide, considerable evidence suggests that a former branch of the Brazos River has been diverted into the Wichita River. Both geomorphologic and stratigraphic observations strengthen the belief for such an occurrence.

Examination of the mapped courses of streams west of

Seymour reveals peculiarities in the patterns of the Brazos and Wichita Rivers. The areal configuration of the Wichita River there, its course directed toward Seymour over a considerable distance and then turning at almost a right angle about six miles away, suggests that it was formerly a tributary of the Brazos River. The junction of the two appears to have been at Seymour, at a large bend in the Brazos River course produced by a change in its general trend from east to southeast.

Examination of the divide between the two streams presents evidence that strengthens the above inferences gained from stream patterns. Two terraces are well developed there, merging with the Brazos River surfaces at Seymour and extending to the northwest toward the Wichita River in an abandoned valley (Fig. 4 and Pl. 11). Each, containing large gravels in deposits that exceed 30 feet in thickness, could have been developed only along a relatively large stream. The only stream that could have flowed across the region of the existing drainage divide during the Pleistocene is the ancestor of the present upper Wichita River, which now splits into two branches, the North and South Wichita Rivers, farther up its valley. The terraces that lie in the old valley are determined to be Lofers and Nixon because of their continuation with equivalent surfaces along the Brazos River. The youngest, Lofers, comprises the flat valley floor, which

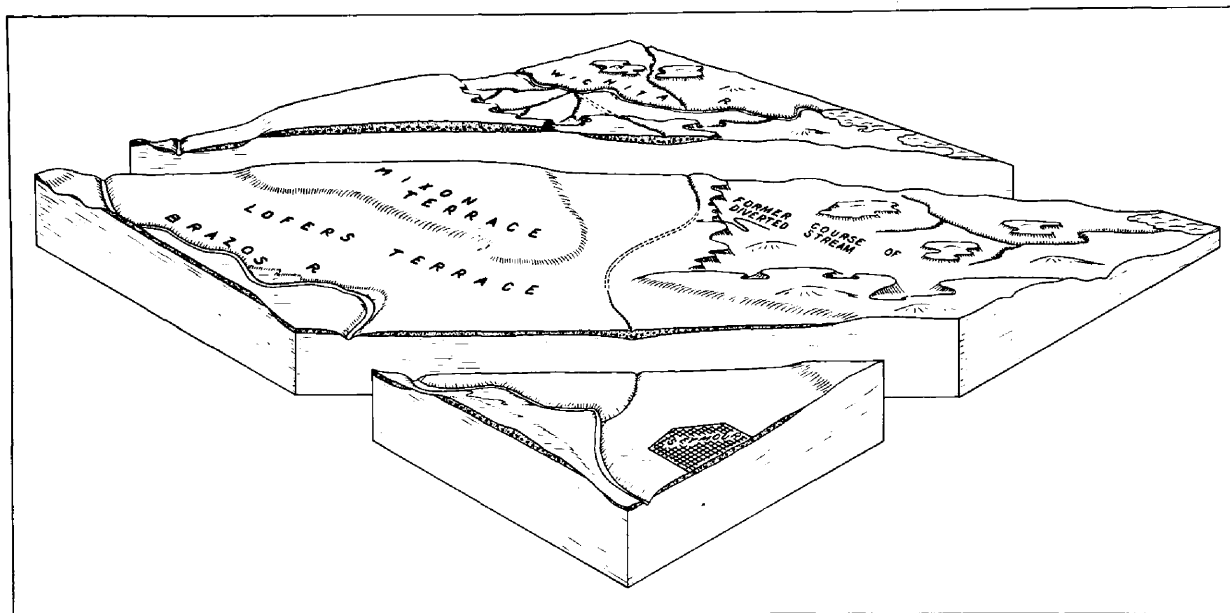


Figure 4 - Block diagram showing the area of the Seymour diversion. The Wichita River, now in the background, formerly joined the Brazos River at Seymour. An abandoned valley floored by Lofers terrace is fronted by Mixon scarp along its only remaining wall, the other having been destroyed by erosion.

CONTOURED MOSAIC SHOWING EVIDENCE OF STREAM DIVERSION

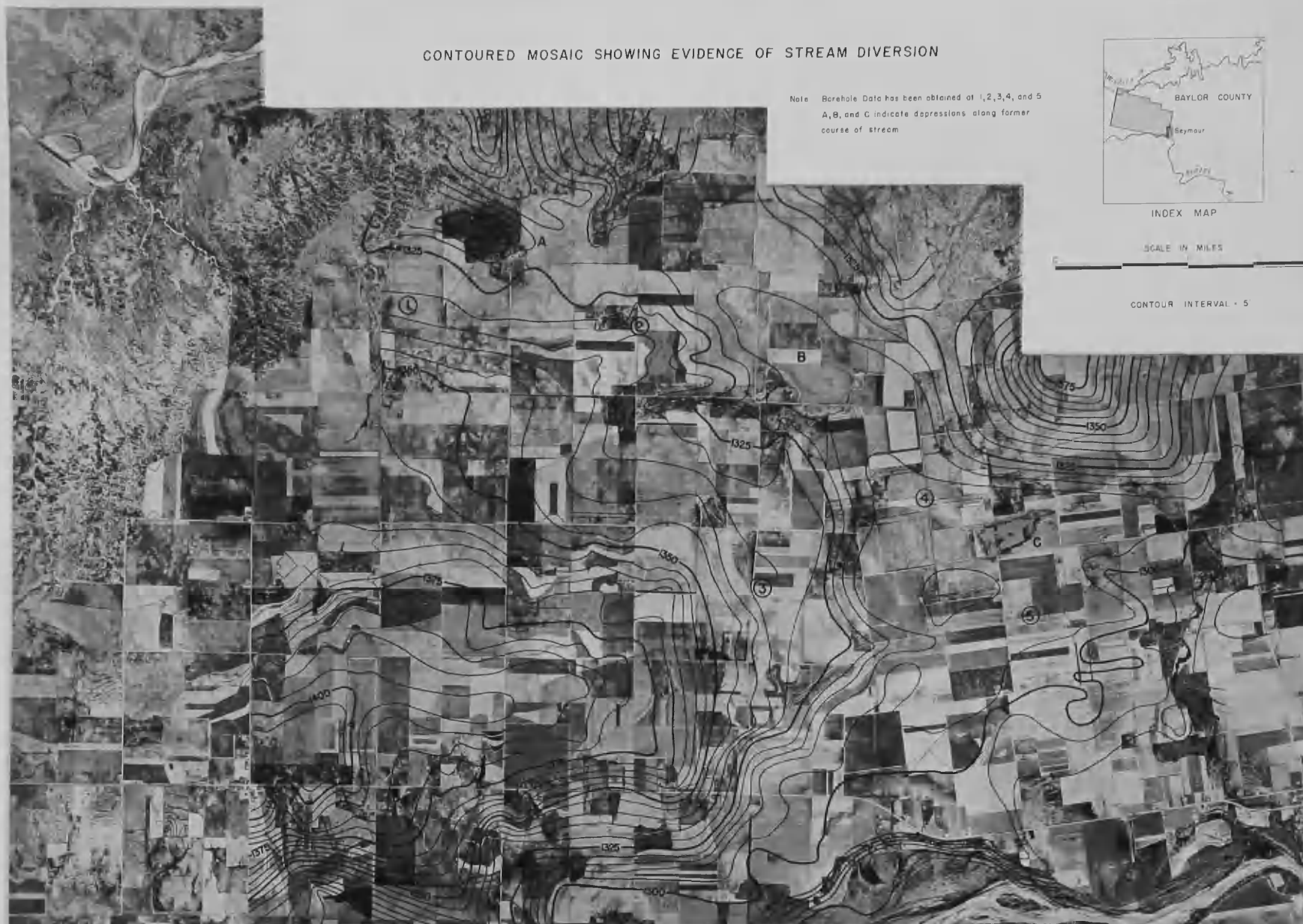
Note Borehole Data has been obtained at 1, 2, 3, 4, and 5
A, B, and C indicate depressions along former
course of stream



INDEX MAP

SCALE IN MILES

CONTOUR INTERVAL = 5



is now poorly drained by a small intermittent stream that flows into the Brazos River at Seymour. Large, rounded depressions, both natural and artificial, at low valley positions probably lie along the filled channel of the former stream (Pl. 11). Lofers formation to the north, lying in the old channel carved in red Permian sandstone, is exposed along the upper steep valley wall of the Wichita River. The ancient valley is flanked on the northeast by a smoothly rounded hill developed on Permian strata, and on the southeast by Nixon scarp, which extends along and fronts the valley.

Borehole data from five wells rather evenly spaced along Lofers terrace (Pl. 11) reveal thicknesses of its deposits as follows:

Well (1)	- 28'
Well (2)	- 30'
Well (3)	- 32'
Well (4)	- 38'
Well (5)	- 42'

These and other data show that the alluvium thickens down the valley, comprising a lens-like body that consists of fine-grained sediments covering a graveliferous sub-stratum. The latter enlarges from eight feet, where it is exposed in the south valley wall of the Wichita River, to approximately 20 feet in well (5), six miles down the valley. Lofers terrace slopes down the valley at about 3.4 ft./mi., comparing with a gradient of 3.2 ft./mi. for the equivalent surface along the Brazos River above Seymour.

Mixon surface, lying at around 1400', is actually the divide separating the relict valley from the Brazos valley to the south. Gravels are exposed along the base of its scarp, which is terminated to the east where the two valleys join.

Lofers and Mixon terraces, and Madrigal farther up the river, continue upstream along the Wichita system above the relict valley. Their gradients and heights above the present channels, upstream from and immediately below the junction of the Wichita and South Wichita River, are similar to those along the Brazos River to the south.

In Knox County the slope of the present South Wichita River is probably very nearly equal to that down which the ancestral stream flowed. Its slope of about 3 ft./mi. compares with the 3.3 ft./mi. gradient of the Brazos River, indicating that there have been no pronounced modifications of the upstream gradient of the diverted stream. Near the Baylor-Knox county line, however, the channels of both the South Wichita and Wichita Rivers, developed on homogeneous Permian beds, steepen probably because of incision that has penetrated more deeply immediately above the diversion. By noting elevations of Lofers terrace in the abandoned valley and along the Wichita River at comparable downstream places, it can be calculated that the Wichita River had at least a 100-foot gradient advantage over the tributary before it was diverted.

Since the drainage change, the channel of the rerouted stream has been steepened immediately above the diversion site by erosion accelerated by this gradient advantage. With continued incision, the gradient will be smoothed by upstream migration, and possible distribution along the channel, of the steepened interval until a normal concave profile is attained.

In the valleys of the North and South Wichita Rivers "badlands" topography presents evidence of erosion acceleration by the diversion. Poorly indurated Clear Fork sandstone, its outcrops strewn with gravel from eroded terraces, has been deeply trenched and sapped from beneath Pleistocene deposits, producing cliff-like scarps along the valley walls. Madrigal deposits are exposed in upper faces of the scarps and in rugged outliers along their dissected margins.

CORRELATIONS AND CHRONOLOGY

The terraces established by this study may be correlated with those noted by earlier workers in this same area and with those that exist in other regions along the Gulf of Mexico. Long range correlations are based on the occurrence of volcanic ash of known age in one terrace among a sequence that is duplicated geomorphologically along large streams of the Gulf Coastal Plain.

The Area Investigated

Earlier investigations of the area under consideration were concerned mostly with the study of older strata, only incidental observations being made of the terraces. Recognizing the geomorphologic continuity of the terraces, earlier geologists adopted the expedient practice of referring to them by numbers signifying their elevations or heights above associated streams. These numbers can in most instances be used to correlate earlier reported terraces with those established by this study (Fig. 5). Uncertain correlations are discussed below.

Disagreements in statements of terrace relief may be ascribed in most cases to inaccurately established elevations and the restriction of earlier studies to local areas only. Terraces recognized in this investigation extend widely,

COUNTY		FALLS		FALLS		McLENNAN		HILL		JOHNSON		PALO PINTO		YOUNG		BAYLOR		CLAY	
AUTHORITY		HATCH		COX		ADKINS		HULL		WINTON & SCOTT		PLUMMER & HORNBERGER		CRISWELL		EVANS		EVANS	
PLEISTOCENE TERRACES	LOFERS	100'	25' 45-50' 90-100'	100'	105'	95'	40' 55' 85'	65'	65'	70'	65'	55'	50'			55'	45-60'	50'	38'
	MIXON	140'	150-200'	140'	160'			145'	125'			110'	90-120'	100'	100'	115'	135'	130'	114-121'
	MADRIGAL	200'	150-200'					190'	165'										
	GERIK											205'	210'						

Figure 5 - Chart showing correlations in the area investigated. Earlier workers have referred to the terraces by numbers designating their elevations or heights above streams.

separated by vertical intervals of about 50 feet. In Falls County, Hatch noted low terraces, probably developed as local surfaces on the flood plain, occurring 25 feet and 45 to 50 feet above low water level of Brazos River. Such minor "cut terraces" may occur on alluvial surfaces as a result of cutoffs and diversions. In this area Lofers terrace, lying at a height of 100 feet, correlates with the "third terrace" of Hatch, who states:

The third terrace reaches a height of 90 to 100 feet above low water level in the river and has a wide areal extent. Remnants of a fourth terrace are found from 150 to 200 feet above low water level in the river.

Remnants of the "fourth terrace," occurring between 150 to 200 feet, have probably been derived from the dissection of Nixon and Madrigal terraces, their surfaces in this area lying at 140 and 200 feet. In this same region in Falls County Cox described two terraces, Prairie and Montgomery, at heights of 105 and 160, which certainly correlate with Lofers and Nixon.

Farther up the Brazos River in McLennan County Adkins also described the flood plain and minor surfaces developed on it at heights of 40 and 50 feet as terraces. His "85 foot terrace" correlates with Lofers.

From Corps of Engineers investigations conducted to locate Whitney Dam in Hill County, Hull concluded that:

Throughout most of Whitney Reservoir area terraces

at two levels occur on either side of the stream . . . the lower terrace occurs at an elevation of 460 feet with a relief of approximately 30 feet and presents itself as a relatively flat alluvial plain about 1,000 feet in width. The upper terrace occurs at an elevation of 510 feet and is a somewhat dissected plain approximately 2,000 feet wide and with a relief of 30 to 40 feet.

The surfaces noted by Hull are extensive beyond the area of his investigation, correlating with Lofers and Nixon terraces. Hull observed higher alluvial deposits, probably those of Madrigal formation, but did not mention their terraced nature in relating:

Nearer the river on top of the high terrace, above an elevation of 510 feet, the overburden is formed of river-transported material, gravel and sand with minor admixtures of clayey silt, and ranges from 15 to 35 feet in thickness.

Here Madrigal terrace is highly dissected, especially away from the river between Whitney and Whiterock triangulation station, four miles south of Whitney, where only resistant basal gravels cap the hills.

In Baylor County along the Brazos River Evans noted two terraces, at 45 to 60 and 135-foot heights, that correlates with Lofers and Nixon. He did not consider higher Pleistocene sediments, those of Madrigal formation, on hills and divides to be of a terrace origin, and followed Cummins in referring to them as "Beymour deposits."

Gravel beds which are commonly present at the base of the Beymour are composed mostly of medium to small, well-rounded pebbles of quartz, quartzite,

cobbles of limestone, and clay balls of local origin . . . Where the deposits have been dissected by erosion, the Seymour is usually easy to distinguish from high terraces of the present major streams by the following criteria; the relatively great abundance of caliche in the Seymour; the Seymour occurs at a higher level on the divides and does not exhibit the riverward dips as is frequently true of the terraces.

The surface, which is well developed on these deposits, is not flat but slopes along the river down the valley like the lower terraces, maintaining a relatively constant height of 160 feet above the river (Pl. 8, Fig. 2).

In Clay County in the alluvial valley of the Wichita River Evans observed terraces at 38, 114, and 121-foot heights, making a distinction between the two higher ones because of the greater thickness, about 42 feet, of deposits associated with the 114-foot surface and the predominantly graveliferous character of the highest sediments, only six feet thick. He concluded that the highest terrace is a basal remnant, formerly more extensive. His lowest surface is that of Lofers and his higher ones are probably both Nixon, the average height of Nixon there being around 130'.

Glacial Chronology

The Pearlette ash, occurring in Madrigal formation and at other widely separated localities in the Great Plains, provides a datum that may be used to establish the glacial chronology of the terrace deposits. Referring to the

Pearlette, Frye, Swineford, and Leonard (1948) state:

Lenticular deposits of volcanic ash associated with fossil molluscs . . . furnish a widespread datum for interregional correlations. The ash lentils, collectively called Pearlette, can be differentiated petrographically from other late Cenozoic ash deposits of the Plains region and have been studied at localities extending from southeastern South Dakota to northwestern Texas. The associated molluscan fauna possesses an unforeseen degree of uniformity and stratigraphic significance. The Pearlette ash and faunal zone occurs above Kansas till in the Missouri valley region and is judged to be early Yarmouthian in age.

In Kansas the Pearlette occurs in the upper part of the Meade formation, which is comprised of two members, the Grand Island below and the Oappa above. In a more recent study of these deposits Frye and Leonard (1952) conclude:

. . . the Grand Island member is retreatal outwash of the Kansan glacier and in areas remote from glaciation equivalent in age to such deposits; and . . . the Oappa member (conformable and gradational with the Grand Island) is a continuation and later phase of this episode of alluviation, perhaps culminating at or slightly after the dissipation of the Kansan glacier. Therefore the Grand Island is classed as late Kansan and the Oappa as latest Kansan and perhaps earliest Yarmouthian.

From the above, the age of the Pearlette is uncertain, estimates of its antiquity ranging from late Kansan to early Yarmouthian. However, it is clear that the glacio-fluvial and fluvial deposits containing the ash were deposited after the beginning of and during the withdrawal of Kansan glaciers from the continent. Since the Pearlette occurs in upper meadrial deposits, about 10 feet below its surface, each of

the other terrace formations are also considered to have been deposited during continental ice recessions elsewhere. The several surfaces, developed on upper soils of the separated sediments, are adjudged to be truly interglacial in age.

Regional Correlations and Considerations

Well developed terrace sequences, geomorphologically the same as those in central and north-central Texas, occur along large rivers in the Gulf Coastal Plain, and some have been dated with Pleistocene chronology. The terraces along the Mississippi River, mapped and studied in detail by Fisk and Russell, have been assigned interglacial ages (Fig. 6) because of their number, four of them corresponding with four interglacial stages, and their obvious relationships to widespread deposition associated with times of glacial retreat by most glacial students. Similar sequences have been described, using the terrace names proposed by Fisk, along the Sabine River (Welch, 1942, and Holland, Hough, and Murray, 1952), along the lower Trinity River (Bernard, 1950), and along the lower Brazos River (Cox, 1949). The studies of the lower Trinity and Brazos Rivers were regional in scope; whereas those along the Sabine River were parish investigations. Terraces in these coastal regions are considered to have developed synchronously with those along the Brazos and Wichita Rivers, so that Prairie, Montgomery, Bentley, and Williana correlate

GLACIAL STAGES			INTERGLACIAL STAGES		INTERGLACIAL TERRACE DEPOSITS				
Each glacial stage characterized by accumulation of ice upon continents and lowering of sea-level with resultant entrenchment of streams and valley cutting.			Each interglacial stage characterized by retreat of ice sheets from continents and rise of sea-level with alluviation of valleys cut during previous glacial stage.		Each terrace deposit is of interglacial age and fills valleys cut during preceding glacial stage. Continued uplift during Quaternary Period has raised terrace deposits above level of present floodplain.				
GLACIATED AREA					LOWER MISSISSIPPI VALLEY	LOWER TRINITY R.	LOWER BRAZOS R.	UPPER BRAZOS R.	
QUATERNARY PERIOD	RECENT EPOCH				RECENT ALLUVIUM				
	PLEISTOCENE EPOCH	LATE WISCONSIN			Valley Cutting				
			PEORIAN			PRAIRIE	PRAIRIE	PRAIRIE	LOFERS
		EARLY WISCONSIN			Valley Cutting				
			SANGAMON			MONTGOMERY	MONTGOMERY	MONTGOMERY	NIXON
		ILLINOIAN			Valley Cutting				
			YARMOUTH			BENTLEY	BENTLEY	BENTLEY	MADRIGAL (includes Peoriae ash)
		KANSAN			Valley Cutting				
		AFTONIAN			WILLIANA	WILLIANA	WILLIANA	GERIK	
		NEBRASKAN			Valley Cutting				

FORMAT MODIFIED FROM FISK

FORMAT MODIFIED FROM FISK

Figure 6 - Chart showing glacial chronology of the Brazos, Trinity, and Mississippi River terraces.

respectively with Lofers, Nixon, Madrigal, and Gerik. This is concluded from the similarity of the terrace sequences, which are uniformly comprised of four surfaces, and the history of their development, which was promoted by events glacially imposed. Heretofore histories of lower valley development have been inferentially associated with glacial events. Periodic incisions evidenced by scarps have been related to times of ice advances elsewhere, and recurrent deposition of sediments now terraced have been associated with times between glacial culminations. The occurrence of the Pearlette ash, which is known to have been deposited after the Kansan glacial maximum, in a terraced deposit of the Brazos River supports these analogies.

Step-like Pleistocene terrace sequences are reported from other rivers in the coastal plain, but have not been dated with glacial chronology. Along the Colorado River, Hill and Vaughan (1898) observed widespread terraces, Uvalde, Asylum, Capitol, and a "second bottom" above the flood plain, around Austin. Those below the Uvalde, which occurs on the divides, lie at heights of 215, 115, and 40 to 60 feet above the river. Along the Rio Grande, Nueces, and Leona Rivers they observed only two extensive surfaces, the lowest occurring around 100 feet below the Uvalde. Along these rivers minor, low surfaces were seen. At the present no attempts are made to correlate terraces in the area under investigation

with those established by Hill and Vaughan. Future studies conducted farther downstream along the Colorado River will probably reveal that lower fluvial surfaces there have coast-wise extensions which may be coextensive with the coastal terraces related to the lower Brazos River system.

PLEISTOCENE EROSION AND SEDIMENTATION

Alluvial terrace sequences, which are common in the southern United States along coasts and in stream valleys, were developed by erosion following each of several episodes of deposition. Evidence of such a succession of events is offered by the alluvial nature of the terrace deposits and their arrangement, each surface occurring at different valley levels and being separated by erosional scarps. The graded nature of the alluvium and the step-like topography of bedrock on which the separated deposits rest also suggest that deposition and erosion during each of the several phases was intense at first and then gradually slackened. In the former the change from basal gravels to finer sediments above indicates that alluviation gradually waned each time before being interrupted by erosion. In each of the initial erosional phases sediments just previously deposited were penetrated by incision and separated as terraces; at the same time previously existing terraces were left at higher positions by the erosional incision. During its later stages incision slackened and gently sloping bedrock surfaces were planed laterally. When alluviation was again initiated these "erosional flats" were blanketed by terrace deposits.

Fluvial terrace sequences are evidence of former valley levels at which stream channels were once established.

Channels alternately were adjusted by incision and alluviation from low positions at the end of erosional episodes to high ones during waning depositional phases. During any one period of sedimentation channels were raised through a height equaling the thickness of the materials deposited. Scarps separating the terraces indicate that the erosion following each episode of alluviation resulted in valley deepening, incision then penetrating both the alluvium previously deposited and the underlying bedrock. Since scarps separate the terraces vertically, erosion has obviously been dominant over sedimentation in controlling valley relief.

The Atlantic and Gulf coasts were also the scene of terrace development during the Pleistocene. Alluviation and erosion there was contemporaneous with that along streams because coastwise surfaces pass without interruption up stream valleys into fluvial equivalents. The deposits of coastwise terraces are deltaic, being comprised chiefly of fine-grained materials transported by lower streams and deposited around their mouths. Scarps are also coextensive from coasts to stream valleys and separate each of the continuous surfaces. Because both scarps and terraces continue from coasts up stream valleys and on account of the fluvial derivation of coastwise deposits, stream behavior is considered to have controlled coastwise terrace development.

Stream Behavior

In a recent discussion of streams, Frye and Leonard (1952) conclude that:

. . . a stream (a) may transport its load of rock debris without net erosion or deposition; (b) may erode its channel and by so doing add to the quantity of material it is carrying; or (c) may give up or deposit some of the rock materials in transit and so decrease its load. Which of these three conditions obtains at any particular place or time is controlled by the interrelation of three measurable factors: (1) the quantity of water moving in the stream; (2) the quantity and character of the rock debris being transported by the stream and available to it, and (3) the velocity with which the water moves, mostly controlled by the stream gradient.

All three conditions--deposition, erosion, and a balance between both--usually exist locally along a stream, but one ordinarily proves to be dominant over any considered length of stream course. Terraced valley topography, which is dominated by alluvial surfaces and their scarps, indicates that sedimentation and erosion alternated in an episodic manner during the Pleistocene.

Influence of Glaciation upon Stream Regimes

The cyclic behavior of Pleistocene streams appears to have been related to continental glaciation. Some streams, which head in the central United States, had their volumes changed by glacial melt waters. Others such as the Brazos received no runoff but appear to have had their regimes changed by glacial effects that extended far from ice borders.

Volumetric Variations

Certainly streams were affected by broad climatic changes that fluctuated according to glacial movements. Rainfall resulting from the intermingling of warm and polar air masses, the latter originating over ice and moving southward under the influence of prevailing winds, must have increased runoff during glacial episodes. Even today cold air, moving from northern latitudes and displacing warmer air from temperate and tropical zones, largely controls precipitation over much of the continent. During the Pleistocene climates of the south were probably pluvial during glacial culminations and arid or mild, much like that of today, when polar air receded back toward the north with melting ice. The regimes of streams there appear to have been influenced climatically so that erosion and deposition alternately accompanied volumetric variations.

Changes in Stream Velocities

Changes in sea level were probably the most extensive result of Pleistocene glaciation. Pioneer glacialists (Daly, 1925 and 1929; Dubois, 1925; Antevy, 1938) have concluded from their investigations that ocean levels were lowered as sea water was evaporated and converted to continental ice and then later raised when the glaciers melted. Low sea

stands, which coincided with glacial culminations, were thought by Russell (1941) to have been at least 300 feet below the level of the present oceans. Studies of glacial deposits have revealed that a number of Pleistocene glacial episodes occurred in both Europe and North America. Therefore, sea levels oscillated in response to sporadic glaciation, their levels at any one time depending upon existing volumes of continental ice. Streams draining into oceans had their velocities changed by the swinging sea levels so that they eroded during times of ice culminations and alluviated when glaciers waned. Both erosion and deposition, the former during falling sea levels and the latter during rising ones, were initiated at coasts and then later extended as "waves" up stream valleys. The upstream limits to which channel lowering progressed during the glacial episodes were probably dependent largely upon the resistance of valley rocks. Lower alluvial valleys, which are developed in poorly consolidated strata, were surely deepened by more rapid flow during each low ocean stand. Alluviation initiated by rising seas probably advanced all the way up valleys previously incised, partially filling them with sediments.

THEORIES OF TERRACE ORIGIN

Most theories advanced for the origin of alluvial terraces in the southern United States have not related the recurrent erosion and alluviation involved in terrace development strictly to Pleistocene glacial episodes. All explanations recognize that both have occurred and that erosion has been dominant over sedimentation in producing the relief of the separated deposits. Obviously Pleistocene valley deposits could not be differentiated if scarps did not divide them vertically. Erosion that separated each of the terraced surfaces of seaward flowing streams and coasts must have penetrated to progressively lower levels after each successive wave of sedimentation. Such erosion, which lowered stream valleys over 300 feet in coastal regions, must have been activated by major geological events, such as land uplift or lowering of seas. The pulsations of erosion could have been initiated by increased rainfall; however, climatically controlled incision would hardly have resulted in a succession of valleys, each lying from 40 to 80 feet below its predecessor. Most theories of terrace origin relate the erosional penetration to epirogenetic land movements, glacio-eustatic sea movements, or combinations of both.

Land Movements

After conducting an investigation of the Atlantic and

Gulf Coastal Plains, McGee (1890) concluded that each of two widespread marine terraces was developed during one cycle--aggradation followed by degradation--which coincided with an oscillation of shores below and above sea level. Such a postulated sea behavior was explained by regional uplift inland, which tilted coasts to lower positions. Marine alluviation along shore bottoms was interrupted both times by vertical uplift of the areas previously submerged, so that each time sediments just deposited were dissected and separated as terraces. McGee thought that deposition on shore bottoms was promoted by uninterrupted stream erosion, since the land was supposedly uplifted continuously; therefore, he considered alluvial surfaces of valleys to be re-entrants of marine terraces. His theory of terrace origin involves land movements only, no mention being made of possible eustatic variations of sea level.

From investigations of Pleistocene terraces in Maryland, Shattuck (1906) arrived at conclusions almost identical with those of McGee, finding more terraces, however, and explaining them by a corresponding number of land oscillations. Both he and McGee believed that each successive oscillation was of lesser amplitude than the preceding, and that during each, terraces were developed below those formed previously. However Shattuck recognized fluvial surfaces, each passing continuously into larger coastwise ex-

tensions, but concluded that they were developed by estuarine deposition in drowned river mouths. No fluvial terraces were postulated because only erosion was considered to have occurred along streams being uplifted continuously.

Doering (1935), who studied coastwise terraces in Texas, reached conclusions similar to those of McGee and Shattuck. All three, working in coastal areas where surfaces are tilted seaward, postulated land movements only. However Doering assigned the tilting to intermittent downwarps of the Gulf Coast Geosyncline rather than uplift landward. Each movement in the geosyncline tilted and exposed to dissection sediments deposited when the land was previously static.

Volumetric Variations of Pleistocene Seas

At the early date of the work done by McGee and Shattuck, the theory of seas thought to be glacially controlled by Pleistocene ice accumulations had not been fully developed. Both they and Doering proposed indirectly that episodes of erosion and alluviation attended oscillating sea stands--positions of seas on continents--caused by movements of the continent. Sloping alluvial surfaces constituted evidence for such a belief. Cooke (1930), however, after investigating Pleistocene deposits of the eastern seaboard, redefined the terrace attitudes by stating:

I have examined maps of every state from Florida

to Connecticut and a few from Mississippi, Louisiana, and Texas but have detected little evidence of warping anywhere.

He appealed to variations in volumes of glacially controlled seas in order to explain the "flat" terraced deposits. A postulated lowering of the seas from a pre-glacial high level was interrupted by stands, during interglacial stages, lying at successively lower positions. Erosion that attended each lowering was interrupted by alluviation during the stands. The seas never reached a previous high level because of incomplete deglaciation between the ice accumulations, each interglacial stage being more icy than the last, and postulated possible subsidence of ocean basins during the entire glacial epoch. According to Cooke, none of the shrunken ice caps that persisted between times of maximum glaciation were as extensive as those at the present.

Land and Sea Movements

More recent work on alluvial surfaces along southern shorelines has re-established that terraces there are tilted. An abundance of evidence there and elsewhere also indicates that Pleistocene seas were glacially controlled through volumetric changes, so that their stands oscillated from low glacial levels to high ones between ice cap accumulations. Possibly erosion and deposition that recurred during terrace development was associated with both land movements and

ocean volumes.

Fisk (1938) and Russell (1940) postulated that terrace development in Louisiana has been regulated by glacio-eustatic oscillations of seas combined with steady uplift of regions landward. Coastwise surfaces have been tilted gulfward, their slope increasing with age, by geosynclinal subsidence beneath the present shores where continuations of the landward terraces are buried. Upstream beyond the warping influence of the geosyncline, fluvial surfaces are parallel, having been separated by uplift. Between times of glacial culminations raised sea levels more than offset the slow upward land movement, so that streams alluviated their valleys. During times of intense glaciation streams incised to lowered sea stands caused by shrinkages of ocean volumes and continued land uplift.

•

ORIGIN OF THE BRAZOS RIVER TERRACES

Most ideas on terrace origin have originated from investigations of coastal surfaces or their fluvial extensions up lower stream valleys. This study along the Brazos and Wichita Rivers has established that Pleistocene terraces are also prominent in upper valleys quite distant from the gulf. Fluvial surfaces there have been followed for 875 miles up the Brazos River and are known to occur in the Wichita valley about 1050 miles from the gulf as measured along existing drainage routes. Along both streams scarps that separate each sequence of terraced valley deposits maintain similar heights, so that the alluvial surfaces are essentially parallel. Because the streams have eroded rocks of varying resistance, valleys in which the terraces occur are diverse, being comprised of three types--alluvial, incised, and braided. On account of the widespread development of the fluvial surfaces and the uniformity of their step-like arrangement in the different valleys, three Pleistocene events are considered to have controlled stream regimes, so that terraces were developed: (1) continuous epeirogenetic uplift of land throughout the Pleistocene, independent of glaciation; (2) climatic fluctuations that varied with glacial cycles, and (3) glacio-eustatic variations in sea level. Responding to the influences of these

•

events, stream discharges of the Brazos and Wichita Rivers were periodically raised and lowered, so that episodes of erosion and alluviation alternated.

Along the Brazos River, which rises on the High Plains and drains into the gulf, the above events combined to promote erosion during times of ice culminations and deposition during the "interglacial" stages. In the comparatively resistant upper and middle valleys, the stream has been controlled climatically, first alluviating and then eroding several times; whereas, similar activity in the alluvial valley has been more closely regulated by swinging sea levels.

The Upper Valley

Evidence seen in both scarps and terrace deposits suggests that the Brazos River was controlled climatically during the Pleistocene. In Knox County the Pearlette ash, deposited shortly after the Kansan glacial culmination and later covered by floodplain sediments during Madrigal time, occurs 875 miles from the gulf as measured along the river. The ash, along with the former Madrigal flood plain, now a terraced surface, has since been separated 160 feet above the present stream by channel incision. Such erosional penetration in the upper valley can hardly be attributed to lowered sea stands that obtained during glaciation. Evidence in the

area investigated and elsewhere relates the incision to climatic variations that attended multiple glaciation.

Lacustrine deposits in interior regions demonstrate that former lakes were larger than those of the present. Their Pleistocene growth has been related in a synchronous manner to glacial advances elsewhere. Lakes Lahontan and Bonneville, classic examples in the Basin and Range region, were many times larger than their present remnants (Russell, 1885, and Gilbert, 1890). Lacustrine deposits in other areas indicate the former presence of lakes now completely dried up. Evans and Meade (1948) have demonstrated that the widespread Blanco sediments of the High Plains were deposited in lakes that developed during a humid period associated with the first glaciation. Such evidence as the above suggests that glaciation produced climates characterized by increased rainfall and low evaporation rates. Under such a climatic influence rivers had their volumes increased and some, such as the Brazos, eroded their valleys. With its flow increased during times of three glacial culminations, Illinoian, Early Wisconsin, and Late Wisconsin, the Brazos River has incised 160 feet since deposition of the Pearlette ash in its upper valley.

As the continental ice waned each time during the Pleistocene, climates became more arid, probably much like that of today, and the Brazos River alluviated valleys

previously deepened when glaciation was intense. Such behavior of a stream alternately eroding and then depositing has resulted in a number of separated valleys, each with its contained sediments representing incision and alluviation that obtained during one climatic cycle. The initial deposits of each valley, coarse gravels beneath smaller materials, suggest that stream flow gradually diminished during each cycle until only fine sediments were carried. Caliche development in upper deposits, especially those of Madrigal terrace, indicates exceptional aridity at the end of depositional episodes.

The Blanco formation, which occurs on the High Plains west of the area investigated, provides evidence of drought that succeeded Nebraskan glaciation. The sediments were deposited in lakes that existed there during humid times of the first glacial advance (Evans and Meade, 1948). When aridity returned during or after the ice recession, the lakes disappeared and wind-scoured erosional surfaces were developed on their deposits.

The Incised Valley

The incised valley of the Brazos River has also been repeatedly deepened and then alluviated several times. Separated valley fillings there occur primarily within loops that have retained their earlier configuration while

growing periodically during the Pleistocene. Such intermittent growth appears to have recurred during depositional episodes, when the river alluviated slip-off slopes and undermined opposite banks by impinging against them. During times of erosion, when the stream incised resistant channel beds, the loops were fixed. Scarps cut during the repeated incisions, now separating the successive slip-off slope deposits at different valley levels, indicate formerly fixed channel positions. In the Fort Graham area, Hill County, courses that existed during incision preceding Lofers and Nixon sedimentation have been restored by locating them below scarps (Fig. 7). Such a restoration shows that the present loops have been enlarged beyond those of the past and that the loops have been displaced laterally, both sidewise and downstream, during each of the successive alluviations. Because of channel movement during deposition, scarps older than Madrigal have been destroyed; therefore positions of early Pleistocene courses can not be established. Erosion has completely removed Gerik terrace along and adjacent to the present channel, and its remaining deposits exist only at positions protected from erosion away from the river.

The repeated incisions evidenced by resistant scarps in the incised valley are, like those along the upper river, considered to have been synchronous with glacial expansion elsewhere, each of the former channels having been carved by

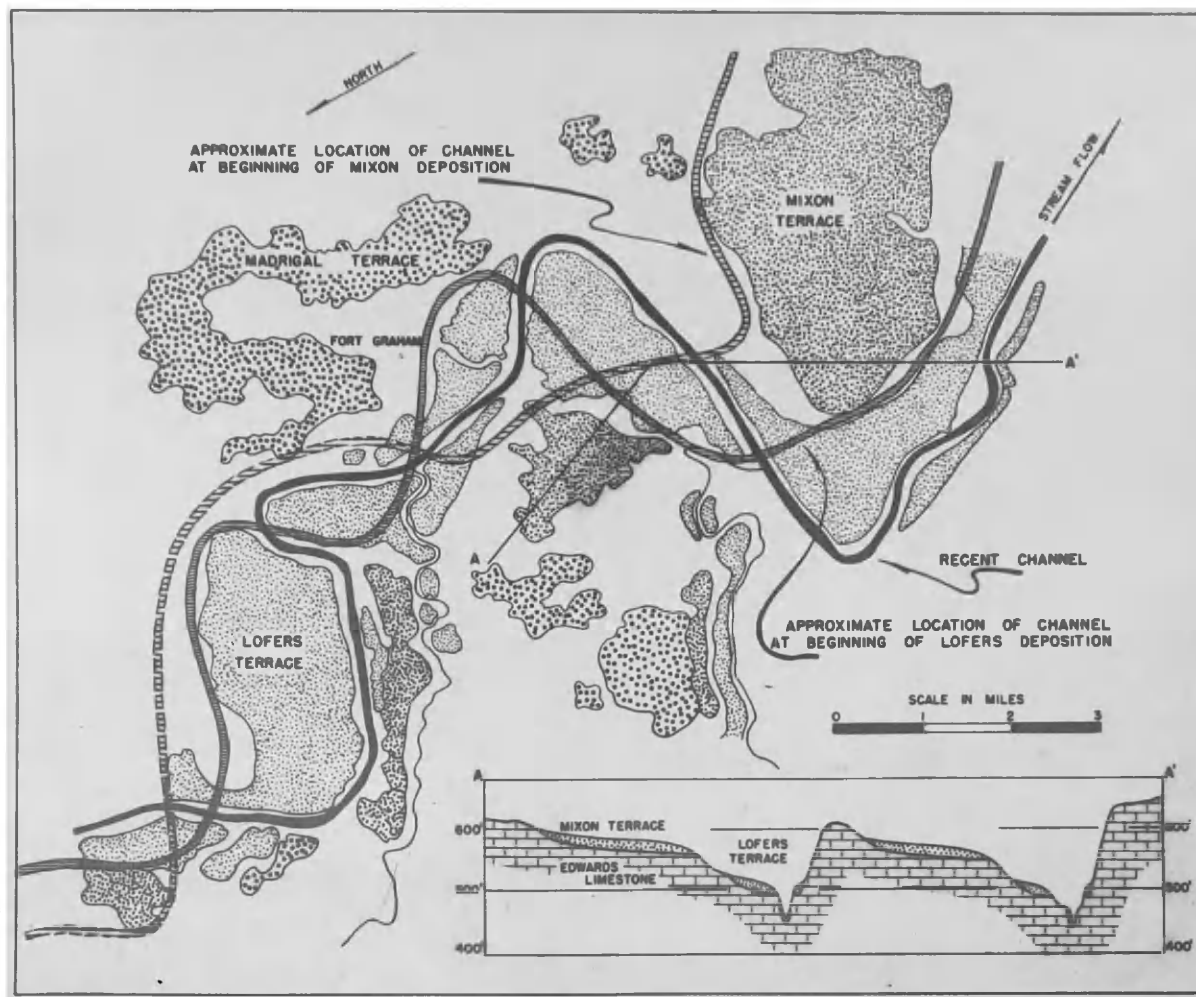


Figure 7 - Map of the incised Brazos River valley around Fort Graham, Hill County showing approximate positions of Pleistocene stream channels.

by streams climatically provided with more water during the ice progressions. During drier times between ice culminations, when water volumes were lowered, streams ceased down-cutting and built up alluvial flats within their valleys.

The Alluvial Valley

The terraces are developed best in the alluvial valley where the Pleistocene deposits are also thickest. Sedimentation occurred very abundantly there during each of the waves of alluviation, veneering the wide valley with thick sections of fine sediments above basal gravels. During recurring erosional episodes sediments previously deposited were rapidly incised, offering little resistance to erosion, and channels were deepened in the poorly indurated bedrock of the alluvial valley. The well-developed terraces there leave little doubt of the erratic behavior of the Pleistocene Brazos River, a stream that periodically alluviated and incised, alternately raising and lowering its valley, according to glacial pulsations. This habit of the stream there was very likely encouraged by undulating sea stands. During falling sea levels stream flow was accelerated at the coast. Incision began there and progressed rapidly upstream in the loosely consolidated sediments of the alluvial valley. When ocean levels began to drop after each glacial maximum, alluviation was initiated at the stream mouth and spread up

the valley. Sedimentation was probably vigorous at first, as is evidenced by abundant basal gravels in each of the terrace deposits, and then gradually slackened as seas were elevated to higher positions.

At the head of the alluvial valley periodic channel incision has exposed resistant strata which maintain the walls of the incised valley farther upstream. Since these beds dip downstream at an angle greater than stream slope, the boundary between the incised and alluvial valleys has progressively moved down the river during each incision. The present alluvial valley, defined by the most upstream occurrence of meanders on an extensive floodplain, begins where the river flows from resistant Austin chalk into poorly consolidated Taylor shale. Downstream from this point all terraces are widespread; upstream the floodplain is narrow below surfaces that are more widely extended, progressively from younger to older. Older terrace distribution indicates that the early Pleistocene limit of a predominantly alluvial valley was southern Hill County. Above there all terraces are restricted to the narrow incised valley. Throughout both valleys the terraces maintain similar heights, indicating that incision has been the same in both resistant and unresistant rocks.

The waves of incision that progressed upstream during each of the lowered sea levels were probably either stopped

or greatly retarded at the first resistant outcrop, that of rocks exposed at the mouth of the incised valley. Since these rocks have been lowered at rates comparable to those of the alluvial valley and since the terraces extend uniformly through both valleys, it is evident that climatically controlled incision has remained apace of that associated with lowered sea levels. Actually both have reinforced each other, causing synchronous downcutting throughout all the diverse valleys. Climatic effects were felt throughout; whereas those associated with undulating sea levels were restricted primarily to the alluvial valley.

Neither climatic episodes nor swinging sea levels explain the excessive channel lowering that has occurred along the entire length of the Brazos River during each consecutive glacial pulsation. If only these two had controlled erosion and alluviation during the Pleistocene, each successive deposit would not be separated by the scarps that enable their differentiation. Since a number of comparable glaciations are considered to have occurred, sea levels approached previous high and low stands during oscillations and climatic cycles were similar. Under such an influence Pleistocene stream incision would not have been as great as that represented by the combined terrace scarps, 160 feet in the upper valley and 230 feet in the alluvial valley. An explanation for the increased depth of erosional penetration during

each successive glacial advance is offered by land uplift. The relatively parallel terraces indicate that such postulated uplift was rather uniform, probably epeirogenetic in nature and not related to glaciation. Therefore it more than likely was continuous throughout the Pleistocene and tended to promote steady stream erosion. However, the movement must have been so slow that it was cancelled during interglacial times by rising seas and streams that carried less water, so that alluviation occurred intermittently. During each of the successive ice accumulations land uplift, annuled during the wave of previous sedimentation and therefore uncompensated by channel adjustments then, combined with lowered sea stands and pluvial climates to promote progressively deeper incision.

BIBLIOGRAPHY

- Adkins, W. S. (1923) Geology and mineral resources of McHenry County, Univ. Texas Bull. 2340, 202 pages.
- Antevs, Ernst (1923) The last glaciation, Am. Geogr. Soc. Res. Ser., vol. 17, 292 pages.
- Bernard, H. A. (1950) Quaternary geology of southeast Texas, PhD. Thesis, Louisiana State University (unpublished), 165 pages.
- Loose, C. A. (1930) Correlation of coastal terraces, Jour. Geol., vol. 38, p. 577-589.
- Cox, C. B. (1949) Pleistocene terraces along lower Brazos River, M.S. Thesis, Louisiana State University (unpublished).
- Criswell, L. R. (1942) Geological studies in Young County, Texas, Univ. of Texas, Min. Resc. Survey Circ. 49, 5 pages.
- Dunnins, W. F. (1893) Notes on the geology of Northwest Texas, Texas Geol. Soc., Ann. Rept. 4, pt. 1, p. 177-238.
- Daly, R. A. (1925) Pleistocene changes of level, Am. Jour. Sci. 5th Ser., vol. 10, p. 221-313.
- _____ (1929) Swinging sealevel of the ice age, Geol. Soc. Am. Bull., vol. 40, p. 721-734.
- Loerling, John (1935) Post-Fleming surface formations of coastal southeast Texas and south Louisiana, Am. Assoc. Pet. Geol. Bull., vol. 19, p. 651-688.
- Labbe, Georges (1925) Sur la nature de oscillations de type Atlantique des lignes de rivages quaternaires, Soc. Geol. France Bull. 4th ser vol. 25, p. 257-278.
- Ward, C. W. (1936) Report on stream terraces with special reference to sand and gravel deposits as a part of mineral resource survey in Clay County, Texas, Univ. of Texas, Min. Resc. Survey Circ. 13, 7 pages.
- _____ (1941) Report on the mineral resources of Taylor County, Univ. of Texas, Min. Resc. Survey Circ. 31, 14 pages.

- _____. (1948) Geology of the Blanco beds of west Texas, Geol. Soc. Am. Bull. 59, p. 617-619.
- Fisk, H. N. (1938) Geology of Grant and LaSalle parishes, Louisiana, La. Dept. Conserv. Geol. Bull. vol. 10, 246 pages.
- _____. (1939) Depositional terrace slopes in Louisiana, Jour. Geomorph. vol. 2, p. 181-200.
- _____. (1940) Geology of Avoyelles and Rapides parishes, La. Dept. Conserv. Bull. 18, 240 pages.
- _____. (1944) Geological investigation of the alluvial valley of the lower Mississippi River, Mississippi River Comm., Vicksburg, 78 pages.
- Frye, J. C., Swineford, Ada, and Leonard, A. B. (1948) Correlation of Pleistocene deposits of the Central Great Plains with the glacial section, Jour. of Geol. vol. 56, p. 501-525.
- _____. and Leonard, A. B. (1952) Pleistocene geology of Kansas, Kansas Geol. Survey Bull. 99, p. 13 and 104, 230 pages.
- Gilbert, G. K. (1890) Lake Bonneville, U. S. Geol. Survey, Mon. 1, 438 pages.
- Hatch, Jesse (1936) Report on a river terrace investigation as a part of a mineral resource survey in Falls County, Texas, Univ. of Texas, Min. Resc. Survey Circ. 6, 3 pages.
- Hill, R. I. and Vaughan, F. A. (1898) Geology of the Edwards plateau and Rio Grande plain adjacent to Austin and San Antonio, Texas, with special reference to the occurrence of underground waters, U. S. Geol. Survey 18th Ann. Rept., p. 243-254.
- Holland, G. C., Roush, E. C., and Murray, G. E. (1952) Geology of Beauregard and Allen parishes, La. Dept. Conserv. Geol. Bull. 27, p. 14-67.
- Hull, A. A. (1951) Geology of Whitney Reservoir Area, Brazos River, Bosque-Hill Counties, Texas, The Woodbine and adjacent strata of the Gaco area of Central Texas, Landren Geol. Serv. No. 4, p. 45-61.
- Matthei, G. J. (1941) Basic aspects of stream meanders, Trans. Am. Geophysical Union, p. 633-636.

- McGee, W. J. (1890) The Lafayette formation, U. S. Geol. Survey, 12th Ann. Rept., p. 347-521.
- Plummer, F. B., and Hornsberger, Joseph, Jr. (1935) Geology of Palo Pinto County, Texas, Univ. of Texas Bull. 3534, 240 pages.
- Russell, I. C. (1885) Geological history of Lake Lahontan . . . U. S. Geol. Survey, Mon. 11, 288 pages.
- Russell, R. J. (1936) Lower Mississippi river delta, La. Dept. Conserv. Geol. Bull. 8, p. 162-193.
- _____ (1940) Quaternary history of Louisiana, Geol. Soc. Am. Bull. 51, p. 1199-1234.
- _____ (1941) Climatic changes through the ages, Year-book of Agriculture, 1941, p. 67-97.
- _____ and Fisk, H. N. (1942) Isostatic effects of Mississippi river delta sedimentation, Am. Geophysical Union, Washington, D. C., p. 56-59.
- Shattuck, G. B. (1906) The Pliocene and Pleistocene deposits of Maryland, Maryland Geol. Survey, 137 pages.
- Welch, R. N. (1942) Geology of Vernon parish, La. Dept. Conserv. Geol. Bull. 22, p. 12-23.
- Winton, W. E., and Scott, Gayle (1922) The Geology of Johnson County, Univ. of Texas Bull. 2229, 68 pages.
- Surface water supply of the United States 1948, part 2, western Gulf of Mexico basins, Geol. Sur. Water-Supply Paper 1113, 1950.

AUTOBIOGRAPHY

Fred Lee Stricklin Jr., the first child of Fred Lee Stricklin Sr. and Sally Martin Stricklin, was born on April 30, 1925, in Ruston, Louisiana. After receiving his elementary, grammar, and high school education at Ouachita Parish High School, Monroe, Louisiana, he enlisted in the United States Navy Air Corps in 1943 and served until the termination of the war. Later, as a student at Louisiana State University, he became interested in science and received two degrees in geology, a B. S. in 1948 and an M. S. in 1950. While continuing graduate work there, he married Glenna M. Jenkins, a fellow student, and later accepted a one-year teaching tenure in 1951 as Instructor in Geology at Baylor University. In 1952 he joined the Shell Oil Company research staff and until the present has continued the work required for a degree of Doctor of Philosophy in geology at Louisiana State University.

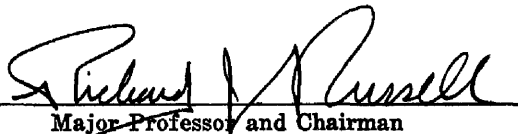
EXAMINATION AND THESIS REPORT

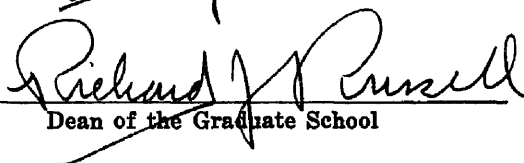
Candidate: **Mr. Fred Lee Striklin, Jr.**

Major Field: **Geology**

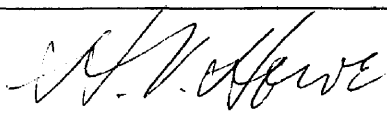
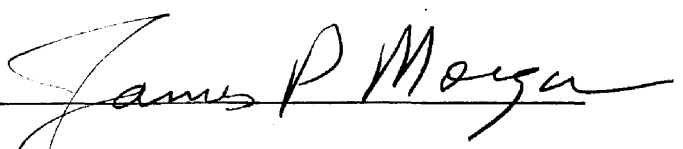

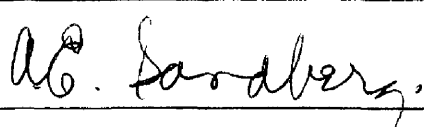
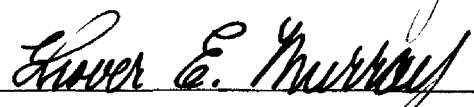

Title of Thesis: **"River Terraces on the Brazos River, Texas."**

Approved:


Major Professor and Chairman


Dean of the Graduate School

EXAMINING COMMITTEE:

Date of Examination:
